ALLIS-CHALMERS Electrical REVIEW

Fourth Quarter, 1947

SLOWLY BUT SURELY science is uncovering many of the sun's secrets. Eventually, science hopes to reduce its findings into practical contribution for better living.

This experimental receiver is one of many throughout the nation used to record the sun's eerie and, as yet, unpredictable signals usually found in the 50 to 500 mc band, and occasionally at 1,300 mc. Physicists contend that a definite relationship exists between these "whistles" and long distance power, telephone, and telegraph lines and radio reception. A future issue of the REVIEW will carry a story on this development.

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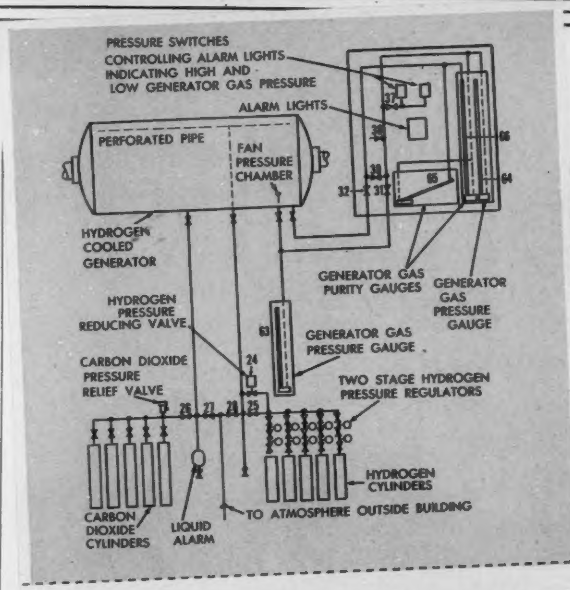

CORRECTED DIAGRAM showing hydrogen and carbon dioxide piping system with valve numbers shown. These numbers for Figure 5, page 9, "Hydrogen Cooling Simplified," Third Quarter 1947 REVIEW were omitted. This revised drawing, with gummed back, will enable you to superimpose it over the old, incorrect illustration. (FIGURE 5)

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The D-C Rotary Dril

E. F. BOENING
Control Section
and
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Smoother application of torque and ease of varying speed are the chief advantages of using d-c rigs for deep oil well operations

OIL WELL operations have followed two significant trends in paving the way for wide application of the direct-current driven rotary drilling rig — gradual conversion to rotary drilling[1] since 1900 until about 90 percent of total footage is now being produced by this method, and the drilling of new wells to greater and greater depths in the search for new fields and the further development of deep pools. Today direct-current drives are resulting in fewer fishing jobs, reducing the chance of losing a well or a string of pipe and the time required to pull and lower a string of drill stem.

As the depth of an oil well increases, two operating problems become increasingly acute. Sudden torque demands by the draw works in hoisting pipe from greater depths eventually exceed the maximum that can be delivered by mechanical prime movers, causing the prime mover to stall and the pipe to freeze in the hole — a very expensive experience. Limits for tensile loading on drill stems also become more important as the depth of the well increases, for not only must the weight of the pipe and drill collars above the bit be considered, but shock loading transmitted to the string of pipe by the rig as well.

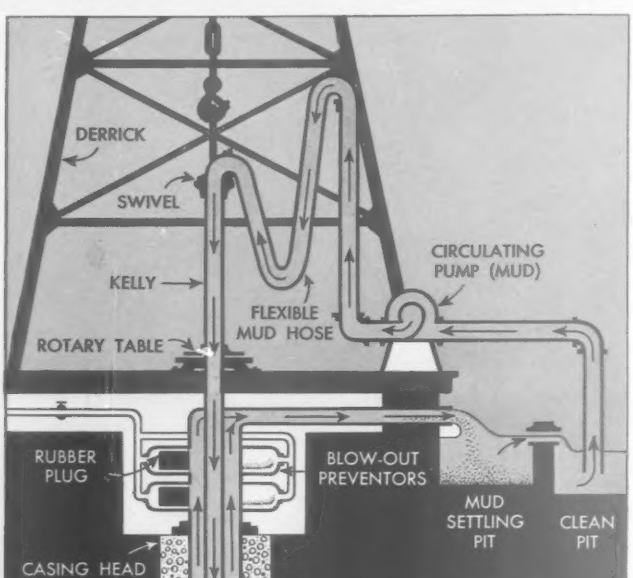
Both of these problems have an ideal solution when a direct-current drive-incorporating direct-current motors, generators, control, and Regulex exciters is applied to a drilling rig. The direct-current drive between the draw works and the prime mover provides a flexible electrical tie and also enables the driller on the derrick floor to vary the ratio between the speed of the prime mover and the speed of the draw works in a great many steps of small increments.

The electrical tie performs another function in that it effectively trades the speed of the motor driving the draw works and the torque that the motor is supplying to the draw works. As the torque demand of the draw works changes while a stand of pipe is being pulled, the d-c motor has available and will develop the necessary torque, within the maximum torque limitations of the motor, to satisfy the requirements of the draw works. A decrease in the torque being delivered by the motor is accompanied by an increase in the speed of the motor; and conversely, an increase in the torque being delivered is accompanied by a decrease in speed. This trading of torque and speed will take place between the maximum torque limitation on the motor and the no-load speed set by the driller and within the horsepower limitation of the generator sets connected to the draw works motor.

Direct-current drives for drilling rigs are designed to

1. Rotary drilling was developed by two brothers, M. C. and C. E. Baker, in about 1882 for drilling water wells in the Dakota Territory, and received its first intensive application from them when they moved to the Corsicana Field after discovery of oil in this North Texas field in October, 1895.

Several wells have been drilled to a depth over 16,000 feet and many others to a depth over 10,000 feet. At present drilling is continuing below 16,996 feet in Caddo County, Oklahoma, on the world's deepest oil well.



Derrick Talk

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To appreciate recent advances in rotary oil well drilling rigs an understanding of the fundamental operations of drilling is important. Here's how they do it in oil fields today:

Drilling

Most wells are drilled by rotating a hollow drilling bit attached to a hollow drill stem. High pressure water and specially treated mud are used to circulate through the hollow drill pipe to bring the cuttings to the surface and to lubricate

SPECIALLY TREATED MUD taken from the clean mud pit is pumped through the flexible mud hose into the kelly and drill pipe. It is then forced up through the cylindrical space into the mud settling pit where cuttings are eliminated by settling. Mud is then used again. (FIGURE A)

illing Rig

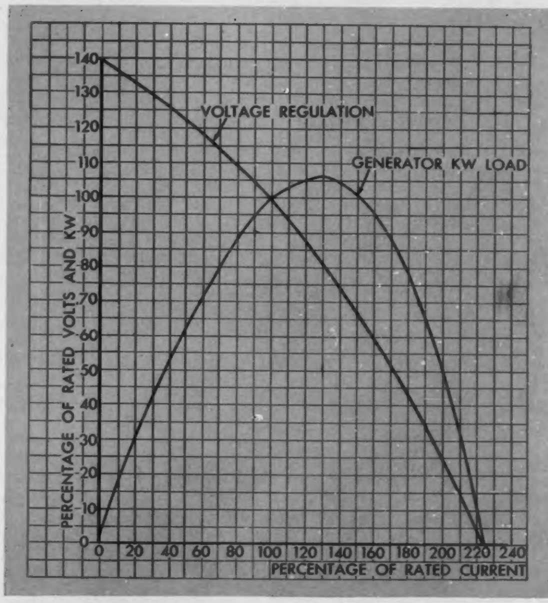
develop momentarily up to 225 percent of their rated torque and develop a no-load speed of approximately 140 percent of full-load speed with rated full-load field current applied to the motor field. This is contrasted with a maximum of about 110 percent of normal rated torque for the diesel mechanical rig.

The field of the motor is excited from a constant potential source. Under such conditions, the speed of the motor, except for the small amount of IR drop through the armature, is directly proportional to the voltage applied to the motor armature by the generator, and the torque developed by the motor is directly proportional to the motor armature current being delivered by the generators. These relations are shown in the equations for rpm and torque.*

The trading of torque and speed of the drive motor, therefore, resolves into a trading of generator voltage and generator current along the voltage curve (Figure 1) and without the product of the two ever exceeding the maximum permissible loading on the prime movers, as is shown by the kw load curve. An innovation in d-c drilling rigs obtains this voltage characteristic by installing a differential series field in addition to a shunt and other control fields in individual Regulex exciters that supply excitation to the main generators.

Maximum torque limitation

The electrical characteristics of d-c electric drilling rigs are such that the individual engines driving the main generators can operate near their rated full load without the possibility of the individual generators demanding more than the maximum that the engines can deliver. This is shown by the generator load curve in Figure 1. This permits the effective use of the engines at near their rated torque and at near full-load efficiency by paralleling only enough generators to handle



TYPICAL GENERATOR voltage and output characteristics obtained when Regulex exciters, incorporating three separate fields, are used. **(FIG. 1)**

the load requirements. When starting a hole, the draw works requires only one or two generators, and as the depth of the hole is increased additional units are paralleled. The table can be handled by one or two units as it is necessary to limit the maximum torque on the drill stem. In addition the control incorporates a current limit on the rotary table drive that helps to accomplish this. *(Continued next page)*

* In these equations K is a constant for the motor involved and ϕ is the magnetizing flux which is also constant in this case.

$$RPM = \frac{K}{\phi}(E - IR)$$

$$T = K \phi I$$

the drill bit, as shown in Figure A. The mud is forced down the drill pipe and up through the cylindrical space between the drill pipe and the outside steel casing. The slush pump circulates the mud through the drill stem while the drill stem is being rotated by the rotary table. It is extremely important to keep the mud flowing at all times. If the circulation of mud stops for a few hours, the drill stem will freeze in the hole because of the settling out of the mud and chips at the bottom of the drill stem.

Hoisting

When the drill bit becomes dull, it is necessary to hoist all the drill pipe out to replace the bit. The pump must be shut down and the kelly and mud hose swivel disconnected from the drill stem. The equipment used to hoist the drill stem is known as the draw works. Since some wells have more than three miles of heavy drill stem in them, torque requirements for the draw works and motor driving the draw works are severe.

The process of hoisting the drill stem, changing the bit, and lowering the drill stem is called "making a round trip." It is highly desirable that the drilling rig have the necessary snap so that time spent in making a round trip is a minimum. A rough criterion for judging whether a drilling rig is well designed is to note the time required to remove a stand of drill pipe, break the joint, set stand aside, and drop the hook. A good drilling rig and crew can do better than one stand per minute. The real test of a drilling rig comes when it is necessary to hoist a long drill pipe that is stuck, since it is then necessary to operate all generators in parallel and have the control function to obtain the maximum available diesel power.

Operation of auxiliaries

Under the category of auxiliaries are the following: shale shakers, mud mixers, ventilators, air compressors, bug fans, and blowout preventers. In the past the motors driving these auxiliaries were generally direct-current, although recently there is a strong tendency to use alternating current in the auxiliaries for modern rigs because of lower first costs of auxiliary controls and motors and the decreased cost of maintenance. *(Continued next page)*

BECAUSE OF CORROSIVE elements commonly prevailing in oil fields, slush pump motors are usually totally enclosed and forced-ventilated for maximum protection against dirt and other contaminating agents. (FIG. 2)

TECHNICALLY, MARINE or swamp drilling is no more difficult than similar operations on solid ground. In marine drilling, power equipment is mounted on barges, as shown above, and moved to the site. (FIGURE 3)

Rotating equipment for drilling, hoisting

The rotating electrical equipment required for a rig consists of motors for driving the table, draw works, mud pumps, and auxiliaries; main generators, auxiliary generators, and exciters.

In selecting rotating equipment for a rig an attempt is made, contingent on requirements of the rig, to select main motors of the same horsepower and speed. This assures maximum interchangeability of parts and continuity of operation.

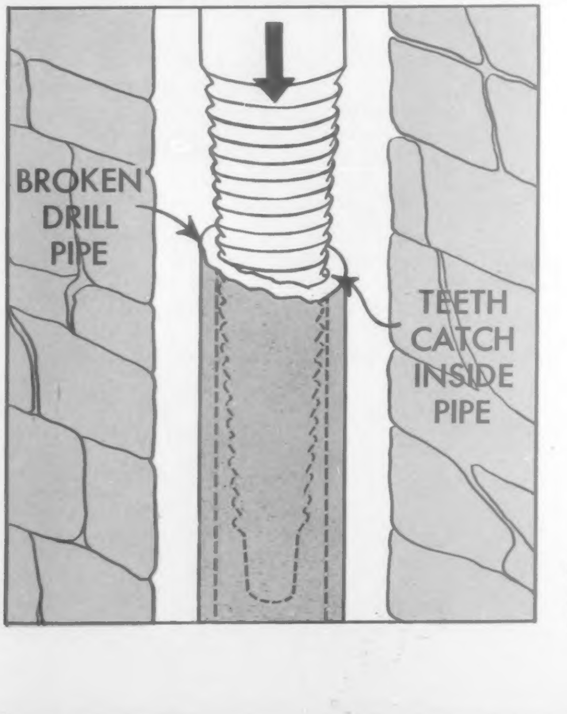
The motors for the table, draw works, and mud pumps, all have totally-enclosed covers and are forced-ventilated from a small motor and blower mounted on each main motor, as shown in Figure 2. A non-explosive mixture of air can be conducted to the blowers where necessary by means of a duct whose intake can be located at a distance from the rig. The use of a blower also assures the main motors of having sufficient ventilation at reduced speeds and full torque.

Draw works motors are mounted on a skid type base with a speed reducing gear. The table motor is usually furnished without a base. Skid type bases are usually furnished with mud pump motors.

The main generators are direct-connected to individual prime movers and have mounted on top a Regulex exciter for exciting the generator field. The exciter is driven from the generator shaft with a V-belt drive.

Auxiliary power and excitation for the main motors is obtained from an auxiliary engine generator set. If a-c auxiliaries are used, it is necessary to have a two-machine set consisting of a constant potential d-c generator to supply excitation to the d-c motor fields and an alternating current generator to drive the auxiliaries.

The rotating equipment is constructed with special parts to resist the corrosive effect of the atmosphere present in many oil fields and has anti-friction bearings which are sealed to prevent entry of dirt. Machines that are not totally-enclosed



Fishing

When the drill stem breaks, the operation known as fishing takes place. After the broken section of the drill stem is removed, a special fishing bit, shown in Figure B, is lowered into the hole and rotated until it engages securely with the broken section of drill. The draw works then function in the normal hoisting manner to raise the pipe, although the control must function so that adequate torque is applied smoothly.

Spudding

By spudding is meant drilling the first few hundred feet. Since the drill stem then does not have sufficient weight to make the drill bit cut fast, it is necessary to lift the drill and then drop it so that the bit gets a good bite. The driller performs this operation very rapidly several times a minute.

Operation of coring reel

The coring reel is a light-duty, high-speed utility hoist generally used for logging purposes and for removing sample cores.

BROKEN DRILL PIPES must be removed from the well before operations can be resumed. A long cone fishing tool with sharp teeth is lowered into the well with sufficient force to wedge teeth into the pipe interior so that the broken segment can be brought to the surface. (FIGURE B)

DIESEL ENGINE-GENERATOR COMBINATIONS

Item	Number of Engine-Gen. Units	Normal Engine HP per Unit	Rated Generator Kw per Unit	Total Maximum Engine HP	Total Maximum Generator Kw	Rated Generators Amps	Maximum Generator Amps
1	4	200	125	940	616	1425	3216
2	5	200	125	1175	770	1785	4020
3	6	200	125	1410	925	2140	4824
4	7	200	125	1645	1078	2500	5628
5	8	200	125	1880	1230	2860	6432
6	9	200	125	2115	1385	3220	7236
7	10	200	125	2350	1540	3570	8040
8	3	300	200	1005	669	1715	3860
9	4	300	200	1340	892	2285	5142
10	5	300	200	1675	1115	2855	6424
11	6	300	200	2010	1338	3425	7706
12	3	450	300	1500	995	2570	5783
13	4	450	300	2000	1330	3425	7706
14	3	600	400	1980	1330	3425	7706
15	4	600	400	2640	1770	4570	10282

FIGURE 4

EFFICIENT OPERATION depends a great deal on the type of equipment selected for a particular drilling job. The drilling contractor, diesel engine manufacturer, and the supplier of electric drive equipment should agree in advance on combinations of standard diesel engine generators to be used as power sources for d-c diesel electric drilling rigs. Once the depth of the hole and rate of hoisting pipe is known, it is a simple matter to select suitable combinations, as shown in the above table. **(FIGURE 4)**

DRAW WORKS MOTOR CHART

Item	Rated Drawworks HP	Maximum Drawworks HP	Rated Motor Torque at Rated Speed	Maximum Motor Torque (Lb-Ft)	Maximum Motor Amps	Voltage at Maximum Amps	Maximum Speed at Maximum Torque
1	600	745	3140	7060	3216	192	550
2	750	928	3930	8850	4020	192	550
3	800	1112	4200	9450	4260	217	620
4	800	1300	4200	9450	4260	253	723
4A	1000	1300	5240	11800	5340	202	577
5	800	1482	4200	9450	4260	288	824
5A	1000	1482	5240	11800	5340	230	656
6	800	1670	4200	9450	4260	325	930
6A	1000	1670	5240	11800	5340	260	743
7	800	1800	4200	9450	4260	350	1000
7A	1000	1860	5240	11800	5340	290	830
8	725	805	3800	8550	3860	173	495
9	800	1075	4200	9450	4260	209	597
10	800	1345	4200	9450	4260	262	750
10A	1000	1345	5240	11800	5340	210	600
11	800	1610	4200	9450	4260	313	895
11A	1000	1610	5240	11800	5340	250	715
12	800	1200	4200	9450	4260	234	670
12A	1000	1200	5240	11800	5340	186	531
13	800	1600	4200	9450	4260	313	890
13A	1000	1600	5240	11800	5340	250	715
14	800	1600	4200	9450	4260	313	895
14A	1000	1600	5240	11800	5340	250	715
15	800	1800	4200	9450	4260	350	1000
15A	1000	2140	5240	11800	5340	333	950
15B	1400	2140	7320	16550	7450	238	680

FIGURE 5

FIRST COLUMN FIGURES of this draw works motor chart indicate the generator combination from which motors would be powered. For example, the seven 125 kw diesel generators listed in Item 4 of the preceding figure are best suited to power draw works motors 4 and 4-A. **(FIGURE 5)**

have drip covers and have screens over all of the openings into the machine.

A considerable amount of today's drilling is done in water or swampy ground. Figure 3 shows the interior of a modern barge supplying all power requirements for the drilling rig which may be some distance away.

Suggested machine ratings

Figure 4 lists various combinations of 125, 200, 300, and 400 kw diesel generator sets that might be used as a power source for d-c diesel electric rigs. For each of the generator ratings a satisfactory engine is listed, with its maximum horsepower rating. The generators can carry a momentary current of 225 percent of the rated current, which limits the maximum current listed in the table. The maximum generator output in the table is limited by the maximum engine horsepower.

Figure 5 lists one or two ratings of draw works motors for each of the engine-generator combinations of Figure 4. The maximum speed at maximum torque and the voltage at maximum amperes is limited by the maximum total engine horsepower in Figure 4, or by the maximum draw works rating. This is true because the maximum speed at maximum torque is limited by the maximum draw works rating, and this, in turn, is limited by the maximum engine horsepower except for combinations 7 and 15 which are limited to a maximum of 225 percent of rated motor current. The maximum motor torque is in pound-feet at a radius of one foot. The draw works motor rating, maximum motor amperes, and maximum motor torque for items 1, 2, and 8 are limited by the generator capacity of the engine-generator sets. From the draw works table it will be noted that, for a particular generator combination, the maximum horsepower rating of the draw works is reached at a lower speed and greater torque with larger draw works motors. Also, with a larger generator capacity the speed of the draw works is greater.

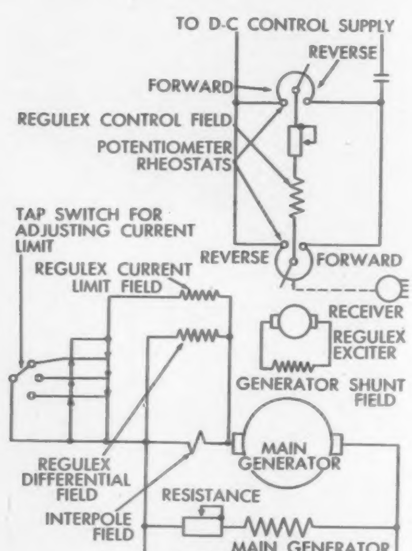
The size of a rig is determined by the engine-generator and draw works motor capacities. After these items are selected, the electrical equipment required for the table, the mud slush and mixing pumps, and for the auxiliaries can be selected to meet the requirements of the rig.

D-C drive control requirements

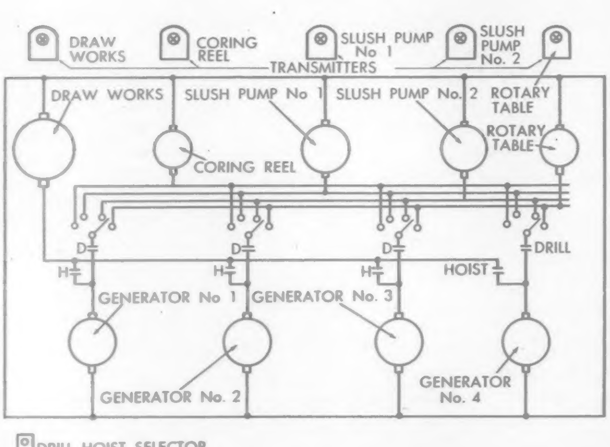
The basic function of the control is to utilize the available horsepower of the diesels most efficiently for the various drilling operations. The control must be flexible so that essential drilling operations, such as keeping the mud circulating, can be carried on during an emergency until necessary repairs are made. Vital control devices must be as interchangeable as possible in order to keep the necessary spare parts down to a minimum. In order to have the rig up and tear downtime materially shortened, the electrical connections should be as simple and foolproof as possible. Equipment must be extremely rugged and must be suitable for rough, portable usage under adverse weather conditions. Control devices located on the derrick floor must be explosion-proof.

To meet these stringent requirements a scheme of control utilizing Regulex exciters and sinusoidal positioners has been developed.

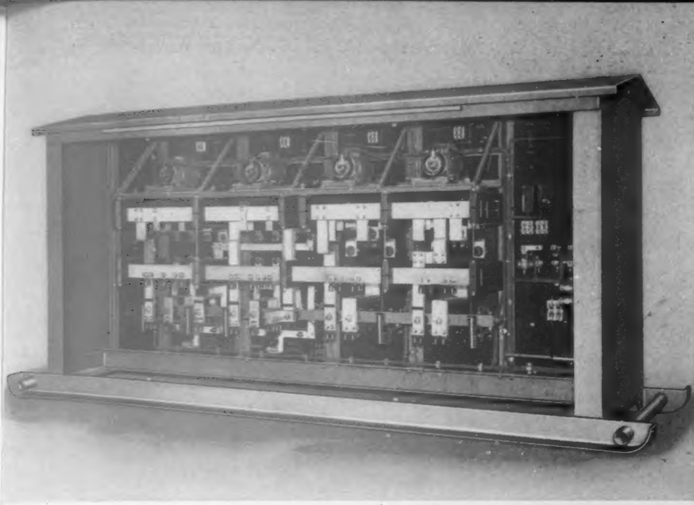
Regulex exciters are used to control the generator voltages in such a manner that the generator output matches the diesel engine capacity. A Regulex exciter is used to separately excite each d-c generator and is connected as shown in Fig-



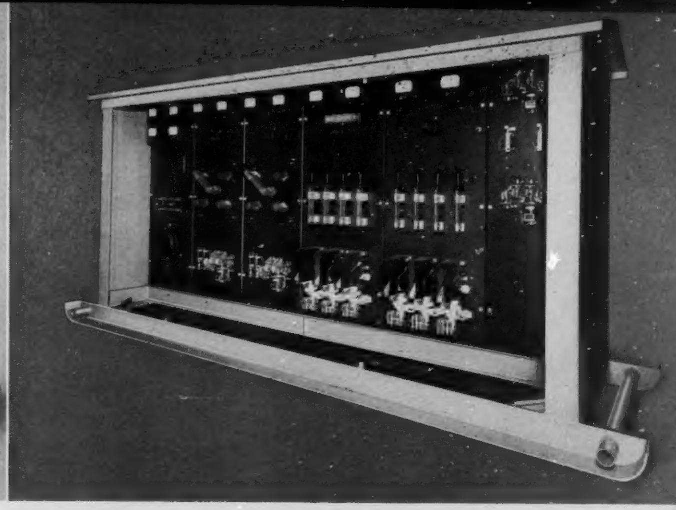
THIS DIAGRAM ILLUSTRATES wiring connections of a typical main generator using three-field Regulex excitation. **(FIGURE 6)**



COMMON LEAD HOOKUP with radial knife switches simplifies switching and gives rig maximum flexibility of operation. **(FIGURE 7)**



BACK VIEW of electrical controls arrangement in a d-c powered drilling rig showing receiver driven potentiometer rheostats. **(FIGURE 8)**



FRONT SIDE of a typical d-c drilling rig control unit showing arrangement of switches, contactors, and rheostats. **(FIGURE 9)**

ure 6. The Regulex exciter has three fields. One field known as the control field is separately excited through a potentiometer circuit, with power generally being obtained from the same exciter that supplies the excitation to the various motors. The main advantage of the potentiometer circuit is that it permits the generator voltage to be reversed without reversing contactors, and also permits very fine generator field adjustment.

Another field of the Regulex exciter, known as the differential field, is connected across the interpole winding of the generator. The purpose of this field is to give the generator a drooping voltage characteristic that will limit the armature current and slow down the motor when heavy loads are encountered. The differential field prevents the diesel engine from stalling due to heavy torque loads and therefore is of vital importance in preventing serious overloading of equipment.

It is possible to increase the bulge in the volt-ampere characteristic of the Regulex-controlled generator (Figure 1) by decreasing the resistance in series with the self-excited shunt field of the generator. This adjustment is important in matching the generator output to the diesel-engine capacity. The current-limit field of the Regulex exciter, used to limit the torque below the maximum available torque, is of particular importance to the rotary table drive where it is desirable to limit the torque to a predetermined safe value in order to prevent breaking of the drill stem when the drill bit encounters a hard formation. This feature is also valuable to the mud pump drives.

The positive resistance characteristic of selenium rectifiers is used in the current limit circuit. By using a tap switch it is possible to vary the number of selenium rectifiers in series with the Regulex current limit field, and thereby adjust the limiting torque.

Sinusoidal positioners

When hoisting pipe from a deep well it is necessary to operate all generators in parallel to obtain the necessary torque. Since each generator is separately excited, the Regulex exciters must be operated in unison for parallel operation of the generators. Parallel operation could also be obtained by supplying all the excitation for the generators from a single Regulex exciter. However, this would be uneconomical and would decrease the interchangeability of various control items.

By employing d-c sinusoidal positioners it is possible to operate the exciters in unison with a minimum amount of control complications and at the same time not sacrifice any of the interchangeability of control items such as potentiometer rheostats and master controls. By installing a d-c transmitter at each control station it is possible to operate by remote control as many as six generators in parallel, merely by having the control potentiometer rheostats receiver-driven and having the receivers connected to the same transmitter.

The d-c sinusoidal positioners provide accurate and instantaneous response without any overshooting. No complicated stabilizing circuits are required to prevent hunting, nor is accuracy of the system affected by d-c voltage fluctuations. The same transmitter is used to operate one or as many as six generators in parallel, and only six small wires are required by the transmitter. Since the current in the control wires is less than half an ampere, mechanical strength need be the only consideration for selecting the size of the control wires.

To keep the main power cable connections as simple as possible, the common lead hookup is used. Figure 7 is a typical switching arrangement. Radial knife switches are used to give the maximum amount of flexibility to the rig. Operation of the radial knife switches automatically transfers the receiver-driven potentiometer to the correct transmitter or control station. Consequently, switching is simple and can be easily taught to an average drilling rig crew. Radial switching equipment and positioners are shown clearly in a typical control cubicle in Figures 8 and 9.

Another desirable feature of the sinusoidal positioners is the fact that they can be used for engine governor control. In engine governor control, the speed of the motor is increased by raising the field strength of the generator through the first part of the speed range and then raising the speed of the engine, permitting the diesels to operate at lower speed, reducing maintenance. However, the application of sinusoidal positioners to engine governor control must be closely coordinated with the diesel manufacturer.

In summary, recent advances in direct-current equipment, particularly in control elements, have established a number of significant advantages for this prime mover in the oil field. The d-c rotary drilling rig will play an increasingly major role in meeting the world's quest for more oil.

SINGLE CIRCUIT Sub

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Substation Section
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SINCE the advent of the first factory-assembled distribution substation some fifteen years ago, the unit substation has gained widespread recognition and approval. Today these substations have been developed to a high degree of standardization and hundreds of them are delivering dependable "on the line" performance. The modern unit substation takes one of two physical forms, either the completely self-contained single circuit substation, which will be discussed here, or the multi-circuit, throat-connected unit, which may be supplied with either one or two transformers.

There are certain requirements which must be considered in the design, application and operation of any distribution substation, whether they be factory assembled unit substations or field assembled "open structure" type substations consisting of single phase transformers, circuit breakers, regulators, lightning arresters, disconnect switches, and fuses. Let us examine these characteristics from the viewpoint of the utility engineer who is responsible for the proper design and operation of the distribution system.

1. *The distribution substation must be reliable.* In case of a failure or an outage due to normal maintenance, facilities should be provided to prevent the interruption of service for any great length of time. Dependable, uninterrupted service is one of the most important, if not the most important consideration as far as the operating engineer is concerned.

2. *The substation must be safe to operate and maintain.* Whether attended or completely automatic, attention must be paid to the design to minimize hazards which would result in accidents. Proper electrical clearances, adequate and protective grounding facilities as well as sufficient bypass facilities for maintenance purposes should be of primary consideration when putting a distribution substation into service.

3. *The substation must be economical to purchase and install.* Since there is approximately eight times as much transformer capacity as generator capacity on the average system, substation costs represent a large percentage of the total distribution equipment costs. Unneeded accessories should be kept to a minimum. Duplication of parts within the substation such as insulators or mounting terminals must be avoided and components must be kept close together to avoid long bus or cable runs. At best, it is very difficult to determine what the installed cost of a substation is going to be, since there are so many variables introduced by the characteristics of the transmission or sub-transmission circuit, capacity, location, service requirements, special features, etc. These variables make it necessary to consider each installation as a separate case.

4. *The substation must be flexible.* Its design must be such that its capacity can be increased and if necessary the substation removed entirely and be replaced by a larger one.

5. *The substation should be adequately protected.* To assure proper transformation, regulation, metering and relaying, necessary protective equipment should be incorporated in the design of the distribution substation.

6. *The substation should present a neat and compact appearance.* This is of particular importance in crowded residential sections. The problem of keeping physical dimensions to a minimum is very important in locations where real estate costs are extremely high. In some instances it is found to be more economical to design the station for underground service. The sound level of the substation must also be kept to a minimum when installed in residential areas as excessive noise cannot be tolerated.

As we have briefly outlined the most essential characteristics of the distribution substation, let us examine the single circuit substation and how it meets these requirements.

In general, the greatest application of single circuit units is in areas of load density where a single feeder, usually 2.4 or 4.16 kv, serves a 1,000 to 3,000 kva load. The standard single circuit unit substation ratings are 750, 1,000, 1,500, 2,000, 2,500, and 3,000 kva. These self-cooled ratings may be increased to 862, 1,150, 1,725, 2,300, 2,875, and 3,650 kva respectively, by means of forced-air cooling equipment. The listed incoming voltages range from 12 to 69 kv, while the feeder voltages are normally distribution voltages in the 5 kv class. All units can be supplied with or without load ratio control. Load ratio control equipment is available to give automatic three-phase voltage regulation of $\pm$ 10 percent. The power circuit breaker can be furnished with a continuous current rating of 600 to 1,200 amperes and an interrupting capacity of 50,000, 100,000, 150,000, 250,000 or 500,000 kva.

Transformer has durable construction

Core type construction is standard for the three-phase power transformer. The core is constructed of low loss silicon steel firmly clamped to give a minimum noise level. The low voltage cylindrical coils are physically adjacent to the core, and the high voltage double disc coils are concentric with the low voltage coils. The design provides liberal oil ducts in the entire assembly so that adequate circulation of oil is assured. The high voltage winding is tapped in the center to minimize distortion under short circuit conditions. These no-load, full capacity taps of 2-2½ percent above and 2-2½ percent below rated primary voltage are brought up to the manually operated tap changer mechanism located on the side of the case.

1. The author wishes to acknowledge the assistance of W. L. Smith, formerly with the Substation Section, in much of the preliminary work of preparing this manuscript.

Single Circuit Subs Are A "Natural" For Today's Utility Needs

SINGLE CIRCUIT substations, suitable for either mobile or permanent service, are fast becoming familiar landmarks at both utility and industrial power distribution installations. This simplified cut-away view with air breaker in the withdrawn position shows the functional arrangement of its operating equipment, consisting of a transformer, complete switchgear compartment, tap changer, and necessary relays and controls. **(FIGURE 1)**

In addition to these no-load taps, standard design can provide automatic load ratio control equipment. With the standard range of $\pm$ 10 percent voltage regulation the mechanism is constructed to utilize 32 steps with 16 steps above rated voltage at rated kva and with 16 steps below rated voltage at rated current. Although the mechanism can be placed in either the high or the low voltage winding, it is usually placed in the low voltage winding when the primary voltage is in excess of 15 kv. The basic design of the load ratio control mechanism has been proven through many years of successful operation in step type feeder voltage regulators.

As shown in Figure 1, the switchgear assembly is an integral part of the single circuit unit substation. Physically the switchgear is mounted parallel to the transformer core and coils, and normally consists of a breaker section and an auxiliary compartment. Both of the switchgear sections are of standard indoor metal clad construction. The breaker section houses either an oil or magnetic air circuit breaker of the draw-out type. Since only one breaker is involved, it is considered standard to utilize a 240 volt a-c supply for electrical closing instead of a 60 cell 125 volt storage battery. This 240 volt a-c control power is converted to d-c by means of a copper oxide rectifier mounted in the breaker compartment.

Switchgear safety features

The stationary portion of the switchgear is equipped with mechanical interlocks to prevent lowering or raising the circuit breaker when it is in the closed position. Also, automatic shutters close off the live stationary bus contacts to prevent accidental contact when the breaker is in the lowered or removed position. All necessary relays and meters are mounted on hinged panels located in front of the compartments. Standard equipment usually consists of three overcurrent relays, a three shot reclosing relay, an ammeter and transfer switch. Although this is considered a normal complement of meters and relays, quite often a ground relay, a voltmeter, and watt hour demand meters are specified. All relays are semi-flush mounted and of the drawout type construction wherever possible.

A single phase, dry type, center tapped control transformer of suitable kva supplies all of the power necessary to operate the power transformer load ratio control mechanism motor, close the circuit breaker, and energize the space heaters, lights and service receptacles. This control transformer does not supply voltage to any metering or relaying equipment. When required, three potential transformers of the proper ratio are furnished with current limiting primary fuses as well as secondary fuses. By mounting the potential transformers and control transformers on drawout carriages in the auxiliary compartment adjacent to the circuit breaker compartment, inspection or replacement is greatly simplified. When load ratio control equipment is supplied, the control panel is mounted on the hinged door of the auxiliary compartment. The load ratio control mechanism compartment as well as the inert gas expansion tanks are mounted above the switchgear structure towards the front of the unit.

Standard outgoing terminations consist of high and low voltage roof bushings, though potheads for underground cable

ALTHOUGH NOT NEW, single circuit substations are the last word in utility and industrial power distribution. Trim, complete, and easily moved and installed, these shop assembled units cost less and require less time to put into operation than the field assembled, open type distribution substations. **(FIGURE 2)**

connections can be specified. When means of isolating the station is desired, a high voltage disconnect switch with pothead can be mounted on the side of the case. High voltage lightning arresters of either the station or line type as well as low voltage arresters can be mounted on the cover of the station.

Meets all requirements

Today's single circuit unit substation, then, conforms closely to the six requisites laid down earlier. By reviewing them in order we can perhaps see why unit substations have gained such universal approval among operating companies in the short length of time they have been available.

1. Reliable service is assured by incorporating the field tested features of three phase power transformers and metal-clad switchgear. Though the idea of the single circuit substation is comparatively new, the equipment which goes into the completed station is not (Figure 2). By coordinating design for the complete layout one manufacturer assumes responsibility for the successful assembly and initial operation and reliability of the overall substation.

2. The completely weatherproofed substation is built with special consideration given to safety features. With protective screens which can be readily placed around the cover, and with the doors padlocked, it is practically impossible for the operating personnel to come in accidental contact with live conductors. The switchgear is mechanically interlocked to prevent incorrect operation of the breaker. All main and secondary control contacts are automatically disconnected when the breaker is lowered from its operating position. The high and low voltage circuits are separated by barriers; while the power circuit breaker itself is completely isolated in its own compartment. A transfer truck is supplied with all units to facilitate inspection and testing of the circuit breaker, as shown in Figure 3.

3. In these days of high labor costs, the tremendous amount of man-hours involved in designing, purchasing and erecting an open-structure type distribution substation has caused a terrific increase in its installed cost. The fact that the factory assembled unit can be purchased in a standardized design allows the user to take advantage of lowered installed cost. The standard design results in savings in engineering and drafting costs as well as actual manufacturing costs. It should also be pointed out that the standard design, in addition to reducing manufacturer's costs, also tends to reduce manufacturing shipping time. Last, but not least, the standard design allows interchangeability of units on a utility's system, thus making for a more flexible and reliable system.

4. Ease of installation is one of the major advantages of the single circuit substation. A single concrete pad is all that is necessary for a foundation*. Overhead lines can be terminated on the station itself through the use of an "A" frame. Accessories such as high voltage and low voltage lightning arresters, disconnect switches and fuses can also be supplied on the substation. An interesting application of the single circuit substation arising from its ease of portability is that of supplying 4,160 volt power for draglines and

SINGLE CIRCUIT substations, though compact and completely self-contained, permit easy access for inspection, testing, and maintenance of all components. This front and side view shows the convenient arrangement of the switchgear portion of a typical single circuit substation. **(FIGURE 3)**

shovels in the larger open-pit strip mines. The substation is placed on skids and moved about the mine, delivering energy to the power equipment wherever necessary. This type of service is certainly a tribute to the rugged construction of the SCS.

5. Almost any protective device can be incorporated in the standard design of the single circuit substation. However, careful consideration should be given to the application of this equipment. Of course the system on which the substation will be placed will determine to a great extent the complement of relays. Blowing of high voltage fuses must be coordinated with relay settings. Derating factors must be applied to automatic reclosing breakers while the application of other protective equipment such as lightning arresters is influenced by the geographical location of the station.

6. The smooth streamlined appearance of the substation is an accepted fact. The symmetrical design allows it to be placed in practically any location, even in residential sections. Its compactness is best illustrated by examining actual dimensions. For example, a 1,500 kva unit designed for operation on a 22 kv system occupies a space approximately 7 x 9 ft in area. A conventional substation of the same capacity would occupy at least three times as much space.

Ratings and sizes of unit substations now cover almost all practical requirements in today's utility practice. There is then, little likelihood of any important changes in additional ratings in the future. And in spite of its convenience, appearance and flexibility the real value of the unit substation will continue to stem from its reliability in service. This in turn can only be achieved by thorough engineering throughout the design, installation and application of the equipment.

* "Installing a Unit Substation," Second Quarter, 1947 ELECTRICAL REVIEW.

TUGBOATS ARE GLUTTONS for punishment. Not a vessel afloat can match them for energy exerted during an ordinary day's work. Introduction recently of diesel electric drives, such as this 814 kw, 700 volt, 700/875 rpm, 1,000 shp unit supplying power for a New York tug, has eliminated much of the excessive strain on equipment. These drives maintain constant motor speed regardless of propeller speed or load conditions.

GROUTING

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EVEN more important than preparing foundations for grouting is the actual mixing and placing of grout mixtures. Type of mixtures, as well as methods of placing grout for best possible advantage, vary according to job specifications.

A generally applicable and good mixture can be obtained by combining one part cement and two parts of well graded sand. For maximum benefits, the water content of the grout should, in all cases, never exceed 50 percent of the cement by weight. When greater flowability of grout is required, the cement content should be increased to maintain the cement-water ratio below .50 by weight. This is done to obtain greater strength and durability to withstand freezing and thawing, shock, high impact loads, or extreme vibration. Low water-cement ratio also reduces shrinkage to a minimum.

Removing excess water

About 16 lbs of water will completely hydrate 100 lbs of cement. Any water required in excess of this amount added to grout or concrete is used only as lubrication. Most of the excess water is lost from bleeding after grout is in place. This water loss accounts for approximately 80 percent of the shrinkage in grout and concrete and also reduces their durability and impermeability.

After the grout has been poured and allowed to settle for half an hour, surplus water and air can be eliminated by rodding. This can best be accomplished by using a suitable length of hoop iron placed beneath the base to churn or work the mixture by long strokes. Another and equally efficient way of dehydrating can be accomplished by using a suitable quantity of well chain with links made of wire of 1/8-inch thickness.

The chains should be placed between the machine base and foundation before the grout is poured. During the pouring period and after the space is filled up, chains should be worked backward and forward. Surplus water and air are thus forced out from between the sole plate or base. To economize on chain, a piece of wire may be attached to either end of the chain for pulling it through the grout.

Types of grout mixtures

Whether or not two mixes of grout are to be used depends upon the distance between the top of the foundation and the bottom of the sole plate or machine base. Sole plates or machine bases up to two feet wide, irrespective of length, should never have less than one inch of grout space at the closest point between base and foundation. For thin grout, the mixture should be one part cement to two parts clear, sharp sand with sufficient water to assure proper grout flowage.

If the width is more than two feet, the depth or thickness of the grout must be increased to four or, in some cases, up to six inches, depending upon the area to be grouted. Mix used on deep grouts consists of one part cement, one part clean, sharp sand and three parts pea gravel or grade crushed stone of equivalent size. Where a six-inch grouting space is required, stone or gravel passing a one-inch mesh may be used. The edge of the grout should be kept damp for several days, depending upon local circumstances, after which a good commercial curing compound should be applied.

Use of dry packing grout is recommended wherever possible. Very satisfactory results are obtained from its use because of its low percentage of shrinkage and the small quantity of water required. Best results can be obtained by mixing a mortar of one part cement and two of sand thoroughly mixed dry. Just enough water should be added so that if the grout is placed in a cone, and the cone is removed while in a vertical position, two-thirds of the grout will remain standing. The grout should be caulked in with four-inch boards of suitable thickness, depending upon the thickness of the grout.

After the grout has set for 18 to 24 hours at a temperature above 70 degrees, the forms may be removed. If the temperature is considerably below 70 degrees, the setting period should be longer. The surfaces are then smoothed with a surfacing stone and pointed up wherever faults, cracks or spalling may have occurred.

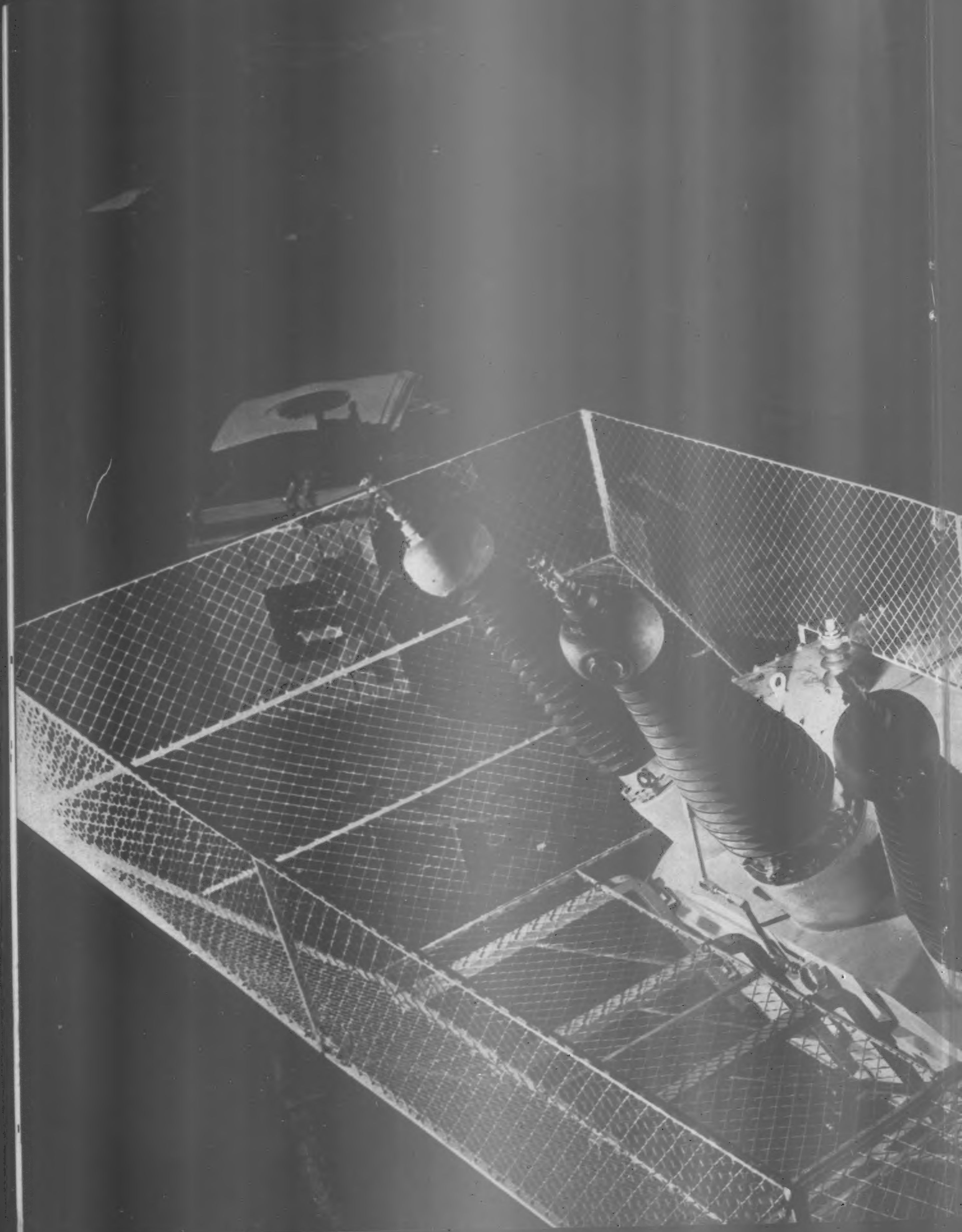
Sealing and setting

In turbine, engine or other foundations subject to relatively high temperature and humidity, the grout joint should be thoroughly sealed with paint or coal tar against the penetration of water from condensation or capillary attraction. Both conditions have a tendency to develop corrosion on sole plates or base of the equipment, ultimately causing lifting or misalignment.

Grout should be left to set for at least seven days before equipment is placed in operation. This is especially advisable if the live load develops vibrations or impact shocks.

Third installment will appear in First Quarter, 1948 issue of the REVIEW and will deal with adjusting and grouting of equipment on horizontal foundations.

SELF-CONTAINED and self-sufficient, this 2,500 kva mobile substation can be placed in operation when and where needed on a moment's notice for emergency or temporary tie-in service. Complete design and application data appeared in the Third Quarter, 1947 ELECTRICAL REVIEW.



Inventions NEED

Ideas, like people, have to retain a record of their identity from birth to maturity

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PATENT rights to an invention are often lost through failure to record all acts with respect to the invention from its conception to the filing of a patent application with respect thereto, and to the time the invention is actually reduced to practice by the building and successful testing of a full size embodiment of the invention, whether a patent application is or is not filed. Working models and records which have been preserved may also be of great value defensively, as where it is desired to invalidate a patent of a third party.

Why keep records?

The fundamental reason for making records is that under the patent laws a patent is valid only if granted to the first inventor. In signing his patent application the inventor must in fact state under oath that he believes himself to be the first inventor.

There are many situations where questions of first inventorship arise, only a few of which need be mentioned here. Assume that a patent application has been filed, is still pending, and that in the course of its prosecution the Patent Office cites a patent, issued less than one year before the filing date of the application in question. This patent includes in its disclosure, but does not claim, some of the subject matter being claimed by the applicant. The attorney at once seeks to determine whether the applicant, under the rules and applicable decisions, can antedate the filing date of the application which resulted in the cited patent.

What the attorney looks for are records. If records can be found legally sufficient to antedate the filing date of the cited patent, the inventor signs an affidavit making oath to facts supported by such records, whereupon the Patent Office withdraws its rejection of the applicant's claims in question and may allow the claims.

On the other hand, if no records can be found, or none legally sufficient to support an affidavit, the patent cited against the applicant's claims in question continues to stand against them and the applicant loses them.

Interference proceedings

An important situation in which first inventorship cannot be decided by mere affidavit arises when two applications are pending in the Patent Office, both of which claim, or can claim the same invention. In this situation, the Patent Office declares what is known as an interference. The purpose of this proceeding is to determine which one of the rival claimants is the first inventor.

The first step in an interference proceeding is for each of the rival claimants to file what is called a preliminary statement. This statement, made under oath, is required by the rules of the Patent Office. Each claimant is required to state, among other things: the date upon which the first drawing of the invention and the date upon which the first written description of the invention were made; the date upon which the invention was first disclosed to others; the date of reduction to practice of the invention.

It is obvious that a preliminary statement cannot be prepared at all unless records are available from which the required dates can be determined. The search for records, made by the inventor, his attorney, and anyone having had anything to do with the development of the invention, must be thorough, for if an earlier record should be found after the statement is filed, the Patent Office can refuse to admit it in evidence.

The preliminary statement is not of itself evidence but serves to limit the testimony a party may thereafter offer to support the allegations of the statement. Testimony is taken in an interference proceeding in accordance with the rules of evidence, as in litigation in a court.

In a case where the sole question is priority of invention, that party to an interference who can antedate the other party by testimony duly supported by records will win. It is outside the scope of this article to mention the many, and often complicated, situations that may arise. It is sufficient to point out that it usually becomes necessary to take testimony as to all activity which followed conception of an invention and resulted in the filing of a patent application or the actual reduction to practice of the invention, or both.

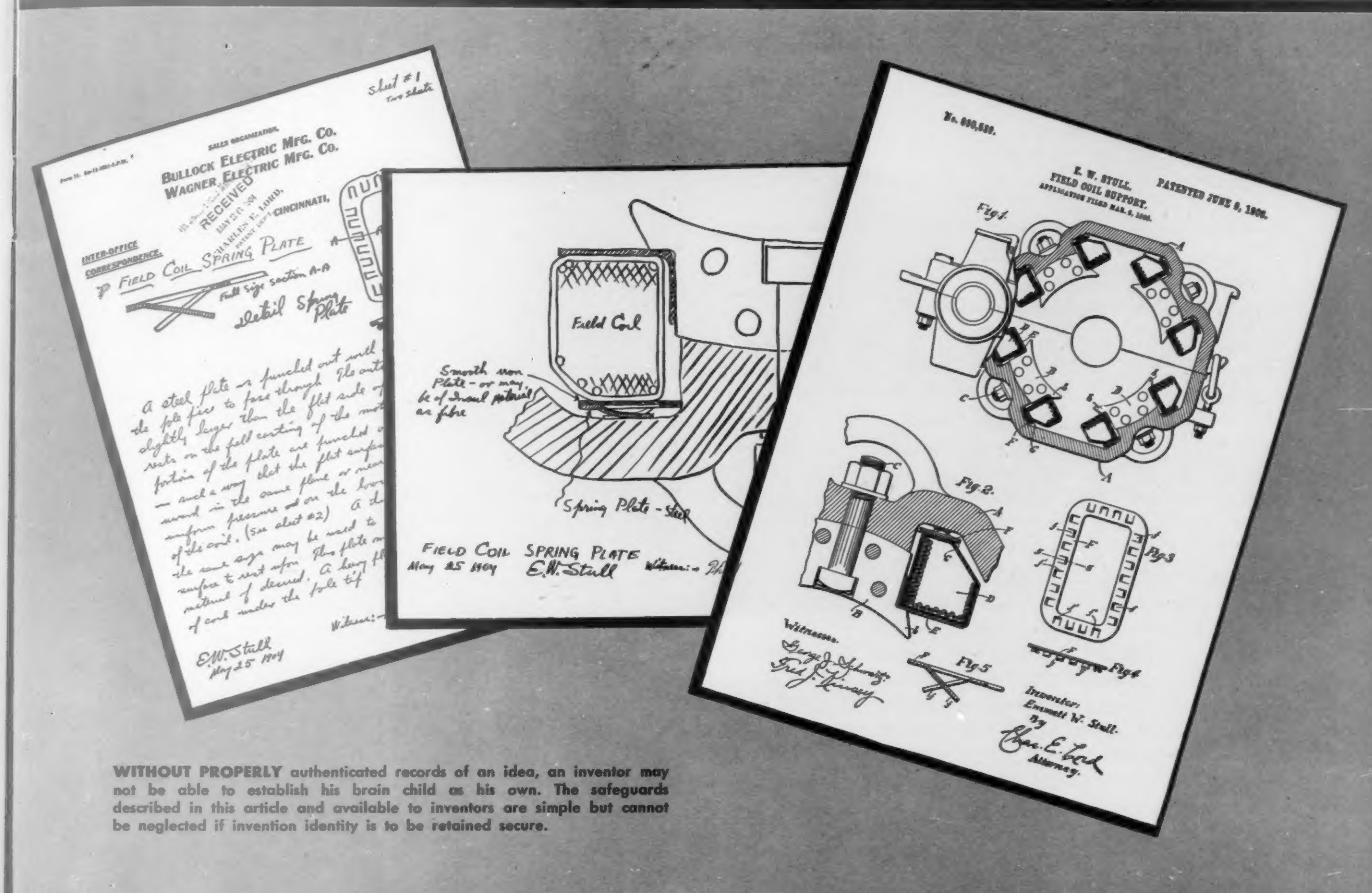
Dates are important

Therefore, besides the date when an invention was conceived and the date when it was reduced to practice, other dates became important, including such as the dates of layout drawings, shop or working drawings, purchase orders, shop time slips, models, photographs, tests and reports thereof, commercial installations, erecting engineers' reports. If records have been scrapped, lost, or are not provable under the rules of evidence, they may leave such a gap in the chain of activities that, under applicable decisions, the party in question loses the interference even though he may be the first inventor.

It is apparent that usually the inventor does not have control over the making of records with respect to all of the acts mentioned. But he definitely has control of the prime acts, which are the making of the original sketch showing the invention, the making of the original description, and the disclosure to others.

An unsigned and undated sketch may serve as a basis for preparation of a patent application, but it is substantially worthless if the question of first inventorship arises and it becomes necessary to prove who made the sketch, and when. A sketch may also be worthless even if the inventor signed

BIRTH CERTIFICATES



WITHOUT PROPERLY authenticated records of an idea, an inventor may not be able to establish his brain child as his own. The safeguards described in this article and available to inventors are simple but cannot be neglected if invention identity is to be retained secure.

and dated the sketch but there is no evidence available that the invention was explained to some other party on that date. The tribunal trying the question of first inventorship will not accept an inventor's unsupported statement that he made a sketch on a certain date, even if the date appears on the sketch. The tribunal requires corroborative testimony.

The best and simplest way for the inventor to lay a foundation for testimony that he is the party who made a sketch on a certain date is to sign and date the sketch and submit it to some other person, capable of understanding the invention, and have the other person sign the sketch as a witness. For the witness' signature to be of any substantial value, the person signing must also apply the date when he applies his signature. The sooner the inventor has his sketch witnessed the better. The effective date of a sketch will ordinarily be no earlier than the date of its first disclosure to another person.

If the invention is the joint product of more than one inventor, each inventor should sign and date the sketch or other paper, and the document should be submitted to some third person for signing and dating. This is because joint inventors are considered together as an entity and hence the testimony of one of the joint inventors will not be accepted to corroborate that of another joint inventor.

Written descriptions are vital

Most engineers make very good sketches, but even a good sketch or drawing ought to be supplemented by a written description. Sometimes, depending upon the subject matter, a written description without a sketch is better than a sketch alone. Judging by experience, many engineers seem to have a special aversion to making written descriptions of their inventions. A written description is not only of great value to make certain the construction and arrangement of the parts of a structure, but to explain the mode of operation of the invention which, from a mere consideration of the structure, is often not apparent at all, or not clear.

Since the sketch is presented as showing something new, something that has never been seen before by others,

it is logical that even a person skilled in the art will not necessarily be able to ferret out the construction and mode of operation of this new thing. He should, therefore, be provided with a written description, not only to save time but for purposes of record and to make certain what may be absent from or doubtful in the sketch. The written description is far more valuable if the parts illustrated in the sketch have reference numerals or legends applied thereto and the written description identifies the parts by their reference numerals or legends.

An original first sketch and an accompanying written description thereof, both signed and dated by the inventor, and both witnessed and dated, constitute the best evidence of conception of the invention. These documents, when properly introduced in evidence, at once prove who conceived, what was conceived, when it was conceived, and to whom and when it was disclosed.

Records must not be altered

Sometimes an inventor describes his invention orally to another person without making a sketch. The testimony of the person to whom the invention was disclosed may tend to corroborate the inventor, but memories are short and faulty, not only with respect to what was disclosed but especially as to the date of the disclosure. Judges are well aware of that fact, and if too long a time has elapsed between the event and the time of taking the testimony, the court will give little or no weight to the testimony.

When a sketch, written description or other record relating to an invention has been duly signed, witnessed and dated, it must not be altered in any way, but should be carefully preserved in exactly the same condition as when signed and dated. If the inventor later thinks of changes or modifications, new sketches and descriptions should be made, and these likewise should be signed, witnessed and dated. It is obvious that if this is not done it will not be possible for the witness to testify that the document offered in evidence is in the same condition as it was when he signed and dated it; and if it is not, it is worthless as evidence for the inventor.

It may be advantageous to have a photostat made, as soon as possible, of an original witnessed sketch and to have the photostat promptly signed and dated by at least one person. But the original sketch must be preserved because original documents are, under the rules, the best evidence.

In the course of the development of an invention after it is conceived and before a full size embodiment is made, preliminary tests of various kinds may be necessary to determine the feasibility of an invention, as for example the testing of materials which it is proposed to use in an embodiment of the invention. Such tests, of course, do not constitute reduction to practice of the invention but they are part of the chain of acts from conception to reduction to practice and hence are important. The names of the persons making the tests should be recorded, and also the date or dates when the tests were made. Reports of tests relating to the development of an invention are usually of great importance yet a report may be substantially useless because, strange as it may seem, the party making the report too many times fails to date it.

Where large machines are concerned, it may be that the first full size embodiment of the invention will be a commercial machine, and technical reduction to practice will not take place until the machine is first operated on the customer's premises. The date of first operation is usually easily determined from erecting engineers' reports or the like. Obviously it would not be feasible to offer a large machine in evidence as an exhibit, and hence the construction of the machine in question must be proved by records such as working drawings and the testimony of engineers and others having to do with the building of the machine.

On the other hand, where a full size embodiment of an invention is relatively small it may be introduced in evidence as an exhibit in the case, provided the history of its making and testing can be satisfactorily proved. Often such working models or devices precede the manufacture of a commercial form of the device and hence are very important to prove the date of the first reduction to practice. If at all possible such early working models should be preserved, and a device which has operated satisfactorily under working conditions should be preserved without change and tagged for identification.

If it is not possible to preserve an original working model then the next best thing is to take photographs of the model, taking care to make some record as to when the photographs were taken, by whom, and what they represent. Often, however, the party taking the picture evidently does not understand that a photograph showing the outside of a totally enclosed electric motor, for example, will not serve as evidence of the construction of the interior of the motor.

The matter of first inventorship also arises where, after the inventor has had his patent duly issued to him, he files suit against an infringer, whereupon the defendant will proceed to make a thorough search for prior records, and possible prior devices or machines which might show that the patentee was not the first inventor or might otherwise invalidate the patent.

Preserve the model!

The keeping of records of inventions and the preserving of working models and the like are not subjects that can be classified as humorous but the writer recalls a decision which illustrates the point of a working model having been found to invalidate a patent, the working model being a crowned tooth in the mouth of a witness!

The plaintiff in the case was a dentist, a Dr. Rynear, who had received a patent on a particular kind of crown for teeth. The defendant was charged with infringement and he managed to find a man who had just such a crown applied to one of his teeth long before the date of Dr. Rynear's invention. In rendering his decision the judge stated:

"At least one of the witnesses called by the defendant swears to a complete anticipation. He testified that a seamless crown was made for him by a dentist in St. Louis, was placed in his mouth in 1877 and was still there at the time of his examination. This crown was examined by Dr. Rynear. The testimony is criticised because the crown was not put in evidence, but, as was suggested at the argument, it is not unfair to assume that the witness may have interposed an objection to having his teeth marked as exhibits in this cause, preferring, rather, that they should remain in his own mouth, so long, at least, as it continued to be 'a going concern'."

DESIGN of Work Coils

PART ONE OF TWO PARTS

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WORK COIL for this operation is connected to the parallel buses located just below the series connections, as shown here. (FIG. 1)

Work coil design, though based on experience, originates in theory

IN less than six years the heating of metals in industry with high frequency power has grown from a laboratory experiment to a very vital tool in a wide section of the metal working industry. This tool has become vital because of the wide range of operations it is capable of performing, and because of the ease with which it may be adapted to any industrial layout in which it must function as a unit.

Up to the present time most of the original high frequency heating installations have been completely engineered by the manufacturer of the equipment. The manufacturer has not only furnished the heater itself but has usually designed and built the work coil and the work handling equipment. In order that the user can determine whether or not an induction heater will prove economical and practical for a given job the heater manufacturer usually processes the original samples of the work. He then has the necessary information to design and build the work coil and work handling equipment to function as a complete process.

After a high frequency heating installation has been made and is functioning properly, it usually becomes obvious that this tool could be adapted to many other jobs in the same plant. In many factories production jobs and designs change rapidly and work coils must be changed to continue production. In the past it has been necessary in cases like these to refer back to the manufacturer for proper coils of new designs. This, of course, is costly in both time and money.

Induction heaters are now becoming so common that many plant or industrial engineers need to know how to design the proper work coil for a given job. Some of the equipment manufacturers have had this in mind for several years, having made changes in their machines to make them adaptable to the many different applications within the power rating of the machine. This was made possible only after much research had been carried out.

Work coil is important link

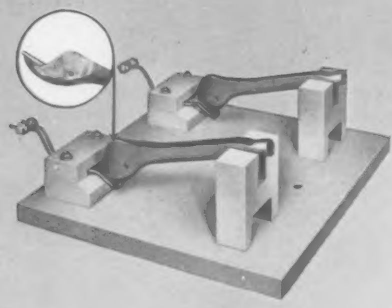
Because the work coil is the link between the generator and the work itself, the characteristics of the unit are important. As has been brought out before, the design should be such that many simple coils will load the machine readily. There are different ways to do this, for example, a self-contained transformer with low-impedance, tuned output, or an external transformer. Since a self-contained transformer provides the most universal method, and one with the least adjustment required, we will use such a unit in our examples.

In a typical heater (Figure 1) utilizing a self-contained transformer, separate output circuits are provided for both series and parallel connections to obtain the best match for both high and low impedance work coils.

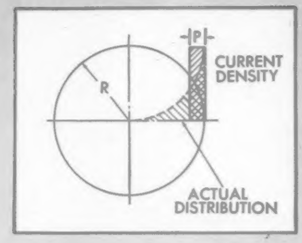
The general design principles outlined here, however, are applicable to all machines although the mechanics of coil construction may vary. The work coil, itself, is considered as that portion of the coil adjacent to the workpiece. In heating by induction there are two possible methods by which heat is induced into the work. One of these is explained easily in terms of I^2R losses, called eddy current losses. When a piece of metal is placed in an alternating magnetic field we know that an electric potential is generated within it. This potential causes a current to flow through the resistance of the material, thus producing losses and resulting in the heating of the metal.

Besides the eddy current loss, magnetic metals are also heated by hysteresis loss. It is not as important as the losses due to eddy currents. The hysteresis loss is the amount of energy absorbed in the material as the lines of flux are changed. The loss depends on the material being heated.

Two variables are controlled with the design of the work coil. The first of these is the selective feature of induction heating. By the proper design of the coil it is possible to effect different temperatures in different parts of the same piece, regardless of their cross-section. This is possible with the right coil as is shown in a typical example in Figure 2. The second variable that may be controlled by the design of the coil is the amount of power to be used or the rate at which the article is to be heated. Often rapid heating would be undesirable even when high production is required. In this case more pieces are heated simultaneously, thus meeting the requirements.



SPECIALLY DESIGNED coils hardened and brazed this wrench part in one operation without either burning or allowing a soft jaw. The small jaw piece (inset) was hardened and brazed to the wrench with silver solder. (FIG. 2)



THIS SKETCH shows the skin effect and depth "P" for a solid conductor. Current distribution curve is much steeper at radio frequencies. Thus thin wall tubing is adequate and provides a passage for cooling water. (FIG. 3)

Characteristics of coil

To get the optimum out of any induction heater, its impedance must match that of the load. The impedance of a coil is made up mostly of inductive reactance. The resistive component of the impedance is as small as possible because copper is used. Silver plating is used where necessary, since it has the lowest specific resistivity. The inductive reactance is directly proportional to the inductance of the coil and the frequency of oscillation. In other words, if over the range of frequencies used for induction heating, the reactance part of the impedance is to be held constant, the product of the inductance and frequency must be a constant. It is plain, therefore, that as the frequency increases the required inductance decreases.

Coil resistance

The resistance of the coil may be found by applying the following equation:

(1) $R = \frac{\rho l}{A}$ where R = resistance in ohms
l = length of material or path in inches
ρ = specific resistivity of the metal
A = area of conducting metal in square inches

(See Table A for actual values of common conductors.)

The actual area which carries current is not the full cross-section of the coil. This phenomena is the result of the skin effect. The current tends to follow the path of least inductance. The current that would flow on the inside of the conductor would cut more lines of force so would encounter more inductance than the current flowing on the outside of the conductor.

Coil inductance

Since we are making a coil which will necessitate a multiplicity of turns, we must consider the effect this will have on the coil inductance. Adjacent conductors carrying current in opposite directions will cause a redistribution of current on the conductor surface. Because of this, theoretical evaluation of the inductance of a coil is very complicated, but it can be found by means of the empirical equation.[1]

(2) $L = \frac{a^2 N^2}{9a + 10b}$ where L = inductance in microhenries
a = outside radius in inches
b = projected length of winding in inches
N = number of turns

It can be shown that at 450 kilocycles, for instance, it is possible that the inductance of the leads themselves can become much greater than the work coil, especially if they are long or spaced some distance apart. This is a very important fact to remember.

Characteristics of load

Let us now look at the load itself. In essence all the different types of loads may be grouped into three general types: ferrous or magnetic loads; nonmagnetic, high resistance loads; and nonmagnetic, low resistance loads. Copper, for instance, is non-magnetic, and has a low resistance; brass or silver would also fall in this group. Under nonmagnetic, but high resistance metals, we would place any magnetic material after it has reached the curie point in temperature, and nonmagnetic stainless steels. In the magnetic group, of course, are all of the metals which exhibit magnetic properties.

In analyzing the heat induced in the metal by eddy currents, we must consider skin effect. Current density in the work is actually distributed as shown by the exponential curve in Figure 3. The area under this curve represents the total current which flows in the piece. Mathematically a much simpler method of using this curve has been devised. The depth to which the current would flow if its density were constant is called penetration factor and is given thus:

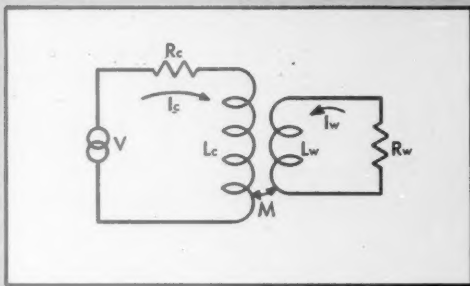
(3) $P = 3560 \sqrt{\frac{\rho}{f\mu}}$

where P = depth in centimeters
ρ = resistivity of material in ohm-centimeters
f = frequency in cycles per second
μ = magnetic permeability of metal

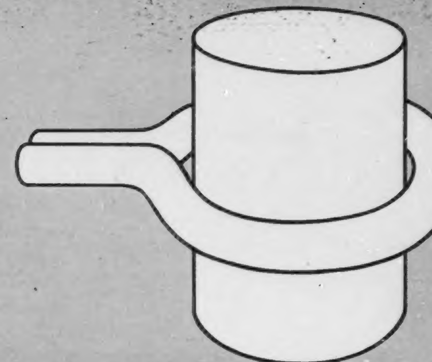
Or in inches:

(4) $P = 1400 \sqrt{\frac{\rho}{f\mu}}$

The following table will give the penetration factors for the different metals calculated at 450 kc frequency.



EQUIVALENT LOAD circuit used in designing work coils. LC is the coil inductance, LW, work inductance, and RW, work resistance. **(FIGURE 4)**



CLEARANCE BETWEEN slug, representing the work, and the work coil in this typical application is approximately one-eighth of an inch. **(FIGURE 5)**

TABLE A

Metal	Resistivity (ρ)	Permeability (μ)	P in inches	Specific Heat
Silver	1.63×10^{-6}	1	2.68×10^{-3}	.056
Copper	1.72×10^{-6}	1	2.71×10^{-3}	.0921
Brass	7.00×10^{-6}	1	5.46×10^{-3}	.092
Stainless Steel	$40. \times 10^{-6}$	25	2.60×10^{-3}	.115
Iron	97.8×10^{-6}	500	9.14×10^{-4}	.161
Steel	45.7×10^{-6}	1000	4.40×10^{-4}	.118

Another point may be applied to all loads presented to the heater, the path of the current in the load itself. It has been explained that the current will flow next to the surface and a quantitative formula has been given. This alone does not completely define this path. When we think of a transformer, we think of a primary and a secondary and this secondary is connected to an outside load. Transformer theory shows that not all of the load is external but there are losses in the secondary windings themselves. The loss is easily located and defined. It is in the wire itself.

In the load of an induction heater we know that the current which is induced in the load by the work coil has a continuous path. To simplify analysis, each turn of the work coil can be considered to be matched with the equivalent of a turn on the work. Each of these turns in the work is shortcircuited. When the turns are close enough the result will be a single turn coil having a width equal to the projected length of the work coil. With this in mind, we can now figure the inductance and resistance of the work itself.

Load resistance and inductance

The resistive component of the impedance of the work may be calculated using equation (1) whether it be magnetic or nonmagnetic. In the workpiece, the width of the path is taken as the total projected length of the work coil. The length of this turn is the circumference of the piece. And, of course, the thickness is the depth shown in Table A.

The inductance presented by the nonmagnetic load can be calculated using equation (2). We again use a single turn coil with the same dimension as for the resistance calculations.

The inductance of a magnetic load is much more complicated. This inductance is given by the formula:

$$(5) \quad L = \frac{3.19\ N^2 \times 10^8}{\frac{l_i}{\mu\, a_i} + \frac{l_a}{a_a}}$$

where L = inductance in henrys
N = number of turns
l_i = length in inches of magnetic circuit in iron
l_a = length in inches of magnetic circuit in air
μ = permeability of material
a_i = area of iron in sq in.
a_a = area of air in sq in.

In evaluating the unknowns in the above equation, we must make assumptions which in general will be reasonably accurate. Assume that the flux penetrates only to the depth which shows heat. The magnetic path then must have the same cross-section as the current carrying portion as shown by the skin depth calculations. The length of this path must be equal to the length of the heated portion or the projected length of the work coil. The length of the air gap will be approximately the same, and the cross-section may be assumed to be equal to twice the cross-section presented by the work.[2]

Mutual inductance

When the work is placed in the work coil the mutual inductance must be defined. We know that

$$(6) \quad M = K\sqrt{L_c L_w}$$

where M = mutual inductance
K = coefficient of coupling
L_c = inductance of coil
L_w = inductance of work

The coefficient of coupling, K, is the ratio of the flux that couples both the work coil and the work, to the total flux. In induction heating the coefficient should be kept as high as possible. This depends upon the spacing and is usually kept above .8.

Since the characteristics of heaters in general is not within the scope of this paper, we must figure the characteristics of the work coil and work as if it were looking into a constant voltage. Actually none of the machines available provide constant voltage. In practice, however, this is not important and it would be impractical and uneconomical to provide it.

The equivalent load circuit is shown in Figure 4. The work

coil is represented as an inductance L_c connected in series with the work coil resistance R_c and the output voltage of the generator V. By the use of Kirchhoff's laws, impedance equations may be derived. In the work coil loop

$$V = \left[R_c + j\omega L_c \right] I_c + j\omega M I_w \tag{7}$$

And around the work loop

$$j\omega M I_c + \left[R_w + j\omega L_w \right] I_w = 0 \tag{8}$$

All of the symbols have been explained except the following:

$\omega = 2\pi f$ where ω = frequency in radians per second
f = frequency in cycles per second

The impedance looking into the work coil

$$Z = \frac{V}{I_c} = R_c + \frac{(\omega M)^2 R_w}{(R_w)^2 + (j\omega L_w)^2} + j\omega \left[L_c - \frac{(\omega M)^2 L_w}{(R_w)^2 + (\omega L_w)^2} \right] \tag{9}$$

The equation shows the effect the load has upon the impedance. As the resistance of the load increases, the total resistance increases since R_w is much less than L_w. As the inductance of the load increases, the total inductance increases, or approaches L_c as a limit.

Actual design calculations

The design of work coils can be made easier by using the formula given here as a guide. The exact evaluation of some of these formulas is impossible without becoming involved. Many assumptions must be made before an answer can be derived. Then each step would have to be retraced, changing each value to discover the effect on the whole.

Resistance losses of the average single turn coil has been found to be about twice that of a conductor of similar cross-section. This gives us the multiple of .5 in the equation below. On multi-turn coils the reduction factor may vary somewhat from this value.

Determining coil characteristics is now practicable. Let us take a single turn coil made out of ⅜-inch copper tubing with a 2⅛-inch inside diameter (Figure 5). Using the respective formulas:

From Equation (1)

$$R_c = \frac{(1.72 \times 10^{-6})\ (2.125)\ (\pi)}{(.5 \times .375)\ (\pi)\ (2.70 \times 10^{-3})} = 7.24 \times 10^{-3} \text{ ohms}$$

The resistivity and depth of penetration were taken from the table.

The inductance of a given coil can be calculated using Equation (2).

$$L_c = \frac{(1.44)^2\ (1)^2}{(9)\ (1.44) + (10)\ (.375)} = .124 \text{ microhenrys}$$

or 1.24×10^{-7} henrys

Calculating impedance of the workpiece is more difficult. As long as the material is nonmagnetic, the problem is not serious. Consider a copper slug 2 inches in outside diameter. Using values from the table.

$$R_w = \frac{(1.72 \times 10^{-6})\ (2 \times \pi)}{(.375)\ (2.70 \times 10^{-3})} = 1.07 \times 10^{-2} \text{ ohms}$$

$$L_w = \frac{(1)}{(9) + (10 \times .375)} = .0784 \text{ microhenrys}$$

The mutual inductance between the work coil and work when K is assumed to be .8.

$$M = .8\sqrt{.124 \times .0784}$$
$$= .0789 \text{ microhenrys}$$

Solution of the impedance equation (9) gives

$$Z = 0.0182 + j\ 0.128 \text{ ohms}$$

If we assume an output voltage of 150 volts we may solve for the current flowing in the load circuit

$$I_c = \frac{V}{Z} = 1.63 \times 10^2 - j\ 1.15 \times 10^3 \text{ Amperes}$$

It is interesting to note that current in the coil actually runs 1160 amperes.

$$P = VI_c = 150 \times 1.63 \times 10^2 = 24{,}400 \text{ watts}$$

We can also calculate the power actually absorbed in the work by first solving for I_w in equation (8) then substituting.

$$I_w = 2.18 \times 10^2 + j\ 1.14 \times 10^3 \text{ Amperes}$$

The voltage appearing across the load would then be

$$V_w = I_w\ (R_w\ j\ L_w) = -2.33 + j\ 12.2 \text{ volts}$$

By multiplying the voltage across the work by the conjugate of the current, the actual power in the work is found:

$$VA = P + jP_x$$
$$= V_w \text{ (conjugate } I_w)$$
$$= 14{,}400 \text{ watts}$$

Therefore the efficiency of this coil would be

$$\frac{14{,}400 \times 100}{24{,}400} = 59 \text{ percent}$$

This value is typical for a copper load. By closer coupling, thus increasing the K factor, efficiency would be increased, but the work handling problem would be greatly increased, since exact centering of the work in the coil at high production speeds is often difficult.

An examination of equation (5) will show why it is impractical to make a theoretical determination of the inductance of a magnetic load. It is almost impossible to calculate the length and area of the flux paths in a magnetic workpiece and in the near vicinity. Where necessary, it is possible to measure the inductance of the piece beforehand with the proper equipment. However, most coil design today has developed from experience, using the equations outlined here as a guide.

---

(1) Equations numbered (2) and (5) have been derived and are accurate only for work at low frequencies. So many additional factors must be added that the equation becomes unwieldy when working at high frequencies. However, the equations are valuable for rough calculation.

(2) The proof for the assumption is quite lengthy. It is based on the effect the work coil has upon the flux distribution.

Protect Your Motors from *Invasion!*

(PART FIVE OF FIVE PARTS)

G. BYBERG and C. D. LAWTON
Motor-Generator Section
Allis-Chalmers Mfg. Co.

Fumes, dust, moisture, and other injurious elements cause more motor failures than mechanical overload

TOTALLY enclosed, fan-cooled motors have been used for almost a quarter of a century and their rapidly spreading popularity is the best indication that industry in general has become fully cognizant of the many factors of advantage they possess.

It is becoming more generally realized that their use under adverse conditions reduces operation costs by assuring longer motor life with less maintenance. In addition, the larger sizes of totally enclosed, fan-cooled motors provide the only possible solution in hazardous locations. Since the type lends itself to outdoor locations, the first cost may actually be less because protecting buildings or structures are not needed. In addition, injuries to personnel due to accidental contact are prevented because all rotating parts are enclosed.

Where continuity of service and reliability are of prime importance, as in central stations or continuous process operations, the factor of maintaining the motor in uninterrupted operation predominates. In such cases, first cost may be relegated to secondary importance.

Because of their now widespread use the demands are for progressively increasing sizes and, at the present time, no definite limitations have been set in the sizes that may be built. However, because of economic reasons, the maximum size for induction and synchronous motors appears to be near 2,000 horsepower.

When protection is needed

The economic justifications of totally enclosed, fan-cooled motors would appear in the amortization of initial and maintenance costs over a specific number of years, as compared to other types which may be permissible for a particular application.

Electrically, there is no fundamental difference between this type of motor and one of the standard open type of the same rating and characteristics. Mechanically there is, however, a vast difference in the external structure. Because the outside air does not come in contact with internal parts of the motor, nor pass through the inside ventilating system, installations in dirty, damp, wet, corrosive or explosive atmospheres may be made.

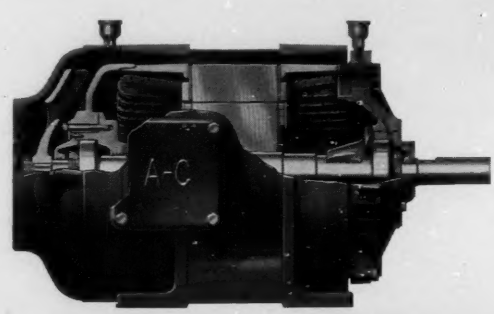
Dirt — A quarry may be using vibrating screens to screen dry crushed stone. A crusher may also be used in this location and cause extremely dusty conditions. Under these circumstances, it would not take long for a motor to become covered with several inches of rock dust. While the dust may not be conducting, an ordinary open motor would probably have its ventilating passages completely clogged, causing it to overheat and materially shorten its life.

In a central station, soot, fly ash, and coal dust may become corrosive when subjected to dampness after the motor is shut down. Such a condition would affect the winding insulation and any exposed live parts, such as brushholders, collector rings, etc.

Oil mist in the air around machine tools in machine shops may cause detrimental deposition of oil on windings and laminations of open motors. Insulation breakdown is hastened with consequent shortened motor life.

Damp or wet locations — In locations subject to dripping or splashing liquids, the use of drip-proof or splash-proof motors is generally resorted to, but even here the totally enclosed, fan-cooled motor's greater protection may be justifiable. If the location is such that floors or walls are frequently hosed down, as in breweries or laundries, the work does not have to be done quite so carefully.

The fan-cooled motor has no equal for outdoor installations. It needs no protection of any sort, and does away



TOTALLY-ENCLOSED, FAN-COOLED motors are secondarily ventilated. This cut-away view of the small general purpose rating variety shows the fan and the circumferential air channels. **(FIGURE 1)**

with buildings, sheds or even a canopy. In hot climates, the motors can be painted with aluminum or other light reflecting paints to prevent excessive absorption of solar heat. And in northern locations, where much snow is encountered, the heat of the motor is usually sufficient to keep it clear of snow, but it may need to be mounted on an elevated foundation to avoid being buried in snow. The use of bearing-oil heaters may be necessary if the motor is subjected to freezing temperatures.

Many pipe lines use this type of motor outdoors for pumping service. Central stations also use motors of this type outdoors for such service as cooling-tower fans and, in larger sizes, for driving draft fans where the installation is generally made on the roof of the building.

Corrosive atmospheres — Totally enclosed, fan-cooled motors are desirable wherever there are corrosive chemical fumes or dusts in the air. Cast iron frames are also frequently desirable but by no means always imperative. On larger sizes where motors are basically of the fabricated steel frame and bearing housing construction, stainless steel or other special materials may be used where the outside ventilating air contacts the ventilating system of the motor. That is, the outside fan, ventilating air passageways and yoke end plates may be made of special corrosion-resisting material.

Chemical plants, where plant operating costs would materially increase without totally enclosed fan-cooled motors, are obviously prominent users of this type of machine.

Ventilation — All totally enclosed, fan-cooled motors are of the secondary ventilated type. That is, there are two heat transfer systems, one inside and one outside the motor. The heat, due to the losses in the machine, is carried by the circulating inside air across the inner surface of the enclosure, from where, by conduction, it passes to the outer enclosure surface and is then carried away by the air stream of the external ventilating system.

Figure 1 illustrates the ventilating system in the smaller or general purpose ratings of motors. The fan on the front end forces a strong blast of cooling air against the front bearing housing, through the circumferential air-channels formed by the two walls of the stator and then out into the room again past the rear end bearing housing. The air passages are streamlined for maximum capacity and minimum windage losses.

With this type of ventilation, the heat dissipating efficiency decreases as the ratings become larger, since the external surface exposed for ventilation and radiation does not increase in proportion to rating increase. Hence, when ratings larger than general purpose are required, the frame size necessarily increases at a considerable rate over that required for an open type. Nevertheless, it must be pointed out that this method of fan-cooling permits a vast improvement over the totally enclosed, non-ventilated type where practical reasons of economy limit ratings to much lower ratings.

Although the above method of fan-cooling has been and still is used on some motors larger than general purpose ratings, recent demands have forced the development of a radically different and much more efficient cooling system in order to keep dimensions, weights, and costs within reasonable limits. This new style of construction used for larger motors is shown in Figures 7 to 10 inclusive.

In this design, the internal air is circulated by rotor fans around a nest of tubes located in the circumference of the stator frame and arranged with their lengths parallel to the rotor shaft. The internal heat is transferred by conduction to the inside of the tubes and is then dissipated to the atmosphere by the air blast passing through the tubes from the external fan.

The sleeve or anti-friction bearings are conventional, but bearing supports usually consist of reinforced steel plates rather than the cast type housing. Internal active parts are, with the exception of some modification of rotor fans, the same as for open type motors of similar frame size. Some of the more pronounced advantages of this type of construction are a lesser increase in weights and dimensions, a simple, fool-proof heat transfer system, no pockets for the entrapment of liquid or dirt, and self-cleaning tubes. The practical limits on ratings are far beyond those of the older method of ventilation. They can be built for lower speeds where previous limitation was the loss in ventilation effectiveness, but which, in this type of construction, can be compensated for by modifications in the heat transfer system.

TOTALLY-ENCLOSED, fan-cooled motors have the necessary protection for operating under adverse conditions. A paper mill installation using 20 hp motors to drive paper stock pumps provides an example of their ability to withstand dirt and grime without loss of operating time. (FIGURE 2)

DUST, LIKE DIRT and grime, presents another adverse condition which lends itself to the use of totally-enclosed, fan-cooled motors. A hammer mill may, at times, produce such extremely dusty conditions that a totally-enclosed, fan-cooled motor becomes ideally suited for that purpose. (FIG. 3)

Hazardous locations defined

The National Electric Code, which is the standard of the National Board of Fire Underwriters, defines Hazardous Locations and lists them into the following groups:

Class I

Group A. Atmospheres containing acetylene.

Group B. Atmospheres containing hydrogen or gases or vapors of equivalent hazard, such as manufactured gas.

Group C. Atmospheres containing ethyl ether vapor.

Group D. Atmospheres containing gasoline, petroleum, naphtha, alcohols, acetone, lacquer solvent vapors, and natural gas.

Class II

Group E. Atmospheres containing metal dust.

Group F. Atmospheres containing carbon black, coal or coke dust.

Group G. Atmospheres containing grain dust.

Class III

Locations which are hazardous because of the presence of easily ignited fibers or flyings, but in which such are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures.

Explosion-proof machines

An explosion-proof machine is one in which the enclosing case is designed and constructed to withstand an explosion of a specified gas or dust which may occur within it, without rupturing, thus preventing the ignition of the specified gas or dust surrounding the machine by sparks or flashes resulting from an explosion within the machine.

The general line of explosion-proof motors is built for Class I, Group D and Class II, Group G locations, the most common applications. These motors are, therefore, not suitable for Class I, Groups A, B, or C locations. The latter three locations are considered more hazardous than Class I, Group D, since those gases form explosive mixtures which, when ignited, develop much higher pressures. Any location requirement below a Class I, Group D can be satisfied by using a Class I, Group D labeled motor. Also Class III locations can be satisfied by either Class I, Group D or Class II, Group G motors, but the fan-cooled type should not be used in places where lint is present in sufficiently large quantities to cause clogging of ventilating passages as, for example, in textile mills.

Class I, Group D locations include such places as gasoline refineries where motors may drive oil or gasoline pumps or other accessories, alcohol and acetone plants, dry cleaning establishments, or paint and varnish factories, gin mills, dyeing plants, plastics plants, etc., where inflammable or explosive gases present are not a greater hazard than high test gasoline vapors and air mixture.

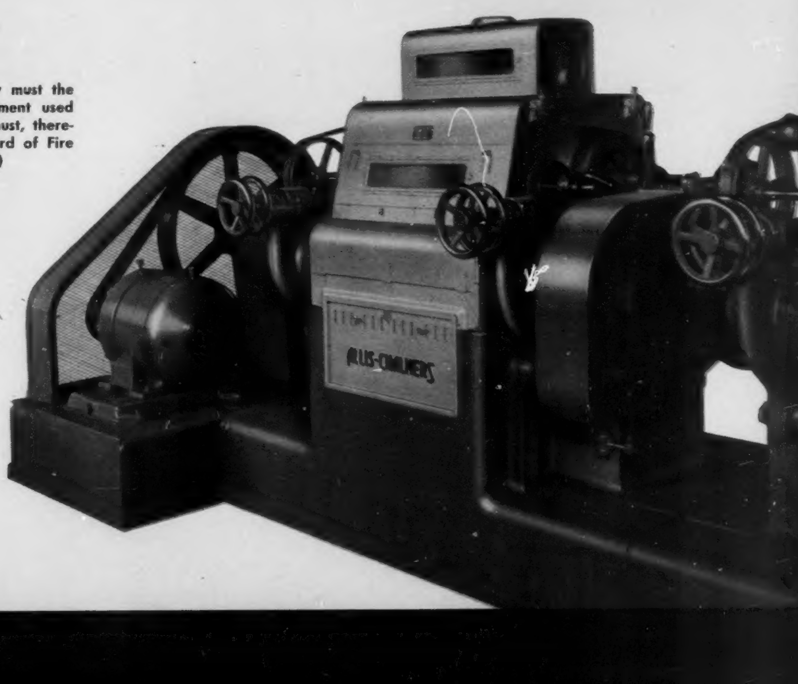
Class II, Group G locations principally include those containing grain dust, as in flour, feed, or grain mills, and include dusts produced in the handling and processing of grain products, pulverized sugar, cocoa, spices, starch, dried potatoes, and wood flour, oil meal from beans and seed, dried hay and other organic materials which may produce combustible dusts.

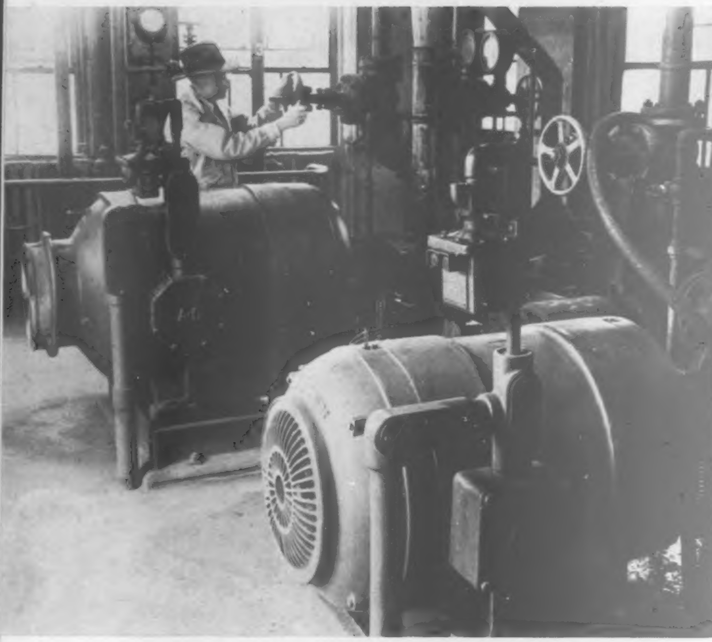
The general principle of construction is as described under totally enclosed, fan-cooled motors, but the explosion-proof motor must fulfill certain other requirements which are described in detail in the National Board of Fire Underwriters' Instruction Bulletin subject 674 for Class I, Group D and Class II, Group G atmospheres.

Briefly, these requirements are as follows:

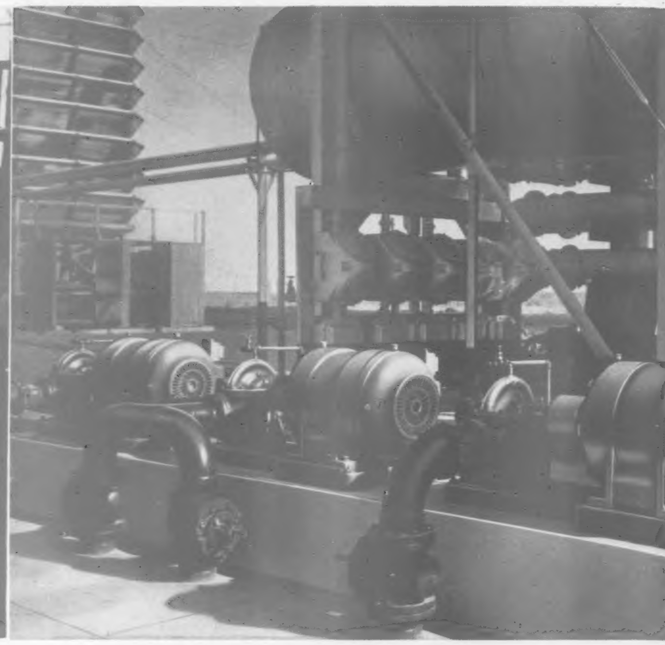
1. The strength of the enclosing parts, yoke, brackets, and shaft seals must be such as to withstand explosions of "Group D" gases within the machine without injury.
2. Any joints, where flame due to explosion may escape, such as between bearing brackets and yoke, must be sufficiently wide or offset to cool or extinguish such flame to prevent ignition of surrounding gases.
3. The conduit terminal box must likewise be enclosed as effectively as the motor itself.
4. The ventilating fan, which is external to the enclosure,

FINE PARTICLES of dust in flour mills are dynamite! Not only must the human element involved be extremely cautious, but the equipment used must be explosion-proof. Motors of individual flour mill drives must, therefore, comply with construction requirements of the National Board of Fire Underwriters' code for Class II, Group G machines. **(FIGURE 4)**





TOTALLY-ENCLOSED, fan-cooled and explosion-proof motors for Class I, Group D locations are built to provide maximum protection against fire and explosion. A typical location of this sort is this view of an oil refinery showing two 100-hp motors driving butane pumps. **(FIGURE 5)**



APPLICATION of totally-enclosed, fan-cooled, explosion-proof motors for driving pumps at an oil refinery illustrates the economy that can be effected where inherent weather-proof construction eliminates building of shelters for equipment intended for outdoor installations. **(FIGURE 6)**

must be so arranged that it cannot possibly hit the adjacent stationary parts and thereby cause sparks. Or it should be made of a non-sparking metal.

Explosion-proof design

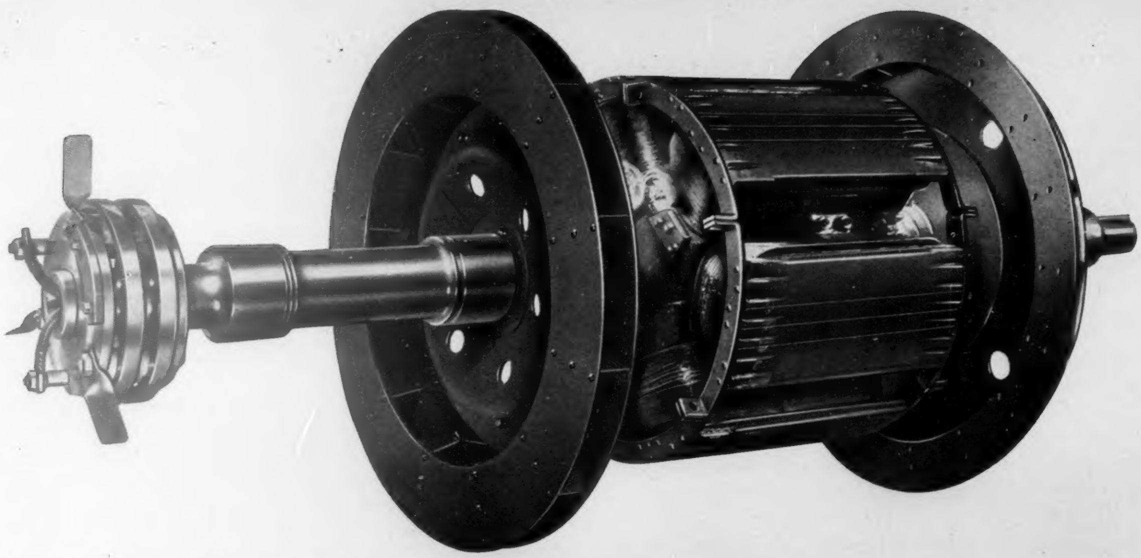
The explosion-proof motor was the outcome of an industry conference arranged between the engineers of the Underwriters' Laboratories of the National Board of Fire Underwriters and the National Electrical Manufacturers Association, with the view of preparing a design specification for a type of motor which could safely operate in atmospheres of explosive mixtures. The first joint conference revealed the fact that a motor designed to operate in atmospheres of highly explosive gases, such as acetylene, hydrogen, ether, and gasoline, would be more costly to build than was thought necessary for motors to safely operate in locations of less hazard, such as grain dust. Therefore, it was decided at the joint conference to prepare a design specification for two kinds of motors, each to meet the two distinct hazards. The two locations were designated by the Testing Laboratories as "Class I" and "Class II" and fan-cooled motors for "Class I" applications have already been described. Since that time, however, it has been decided that all motors for Class I, Group D and all Class II locations will be built of the same construction.

In general, the principle of design of this motor is similar to the totally enclosed, fan-cooled motor, with modifications in mechanical detail to safely withstand the effects of internal explosions.

Considering, for example, the smaller ratings illustrated in Figures 4 to 6, the explosion-proof construction — subject, of course, to design changes — differs from the standard in approximately the following manner:

1. Bearing housings at both ends are of heavier construction, thoroughly ribbed and the rabbet fit to the stator frame is longer.
2. Larger and additional cap screws made of an alloyed steel for securing the bearing housings to the stator frame. Holes, drilled and tapped for bearing cartridge cap screws, do not extend through the cartridge.

THIS 300 HP, 705 rpm cage motor for driving a central station induced draft fan is typical of the construction of larger ratings. This type of construction ranges above approximately 1/3 hp per rpm. **(FIGURE 7)**



EXCEPT FOR SLIGHT modification of rotor fans, rotors for totally-enclosed or open motors are identical. Field leads of rotor for a six-pole, enclosed, sleeve-bearing synchronous motor of the larger size are brought out through the shaft to the collector assembly. **(FIGURE 8)**

3. Bearing cartridge designed with long inner seal to prevent possible creepage of flame to outside of motor.

   The bearing seals are of bronze, to prevent the generation of a spark in the event that the rotor shaft drops from any cause and comes in contact with the seals. They are longer, giving a greater creepage distance so that, in the event of an internal explosion, the gases will come in contact with an area of metal sufficient to reduce the temperature below the ignition point when leaving the confines of the motor.

   Inner seals are pulled against the bearing housing with cap screws that screw into pockets so that if one should become dislodged or not put in place, the interior of the motor is sealed against contact with outside air.

   Airgap apertures are omitted to avoid the possibility of an opening from inside to outside if the pipe plug, which is normally used, becomes dislodged.

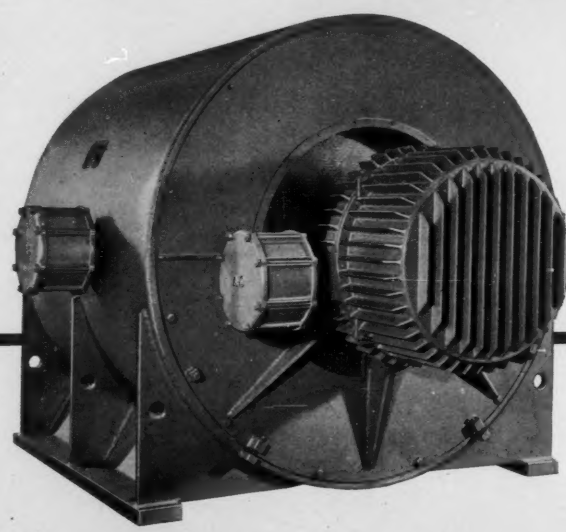
4. Heavy, nickel steel cap screws secure bearing housing to stator frame.

5. Cast iron, explosion-proof conduit box adjustable to four positions.

   Only three leads are brought from the stator winding to the terminal box, making this motor suitable for one voltage connection only. This permits, in the opinion of the Underwriters, to more thoroughly and substantially seal the motor at this point.

It is easily appreciated that an explosion-proof motor for the Class I locations must not only be strong enough to with-

WHEN ASSEMBLED, heat exchanger tubes in the stator frame of a large, totally-enclosed, fan-cooled motor resemble a tube boiler assembly. Construction eliminates contact of the outside ventilating air with all internal working parts as well as the outside of the stator core. **(FIGURE 9)**



EXTERNAL APPEARANCE of large wound rotor induction and synchronous motors (or generators) is identical to the lines of this 500 hp. ten-pole wound rotor motor built for a chemical plant. **(FIGURE 10)**

stand explosion pressures, but that all joints must be tight enough and long enough that in the event of an internal explosion the gases will be sufficiently cooled by the time they leave the motor to prevent ignition of surrounding explosive atmospheres.

In testing a motor for Class I locations, explosive mixtures are pumped into the motor so that when ignited the maximum explosive pressure is obtained. This motor, so loaded with gas, is placed in a gas-laden compartment and, while operated, the gas inside of the motor is ignited. If the surrounding gas in the compartment does not ignite, the motor has satisfactorily passed that one test. There are many tests made on each motor — explosive mixtures carrying different kinds of gases, and of varying percentages.

This motor should not be confused with the type required by the Bureau of Mines, as the two are entirely different. The Bureau of Mines specification is more rigid because of the additional hazard to human life in underground operations.

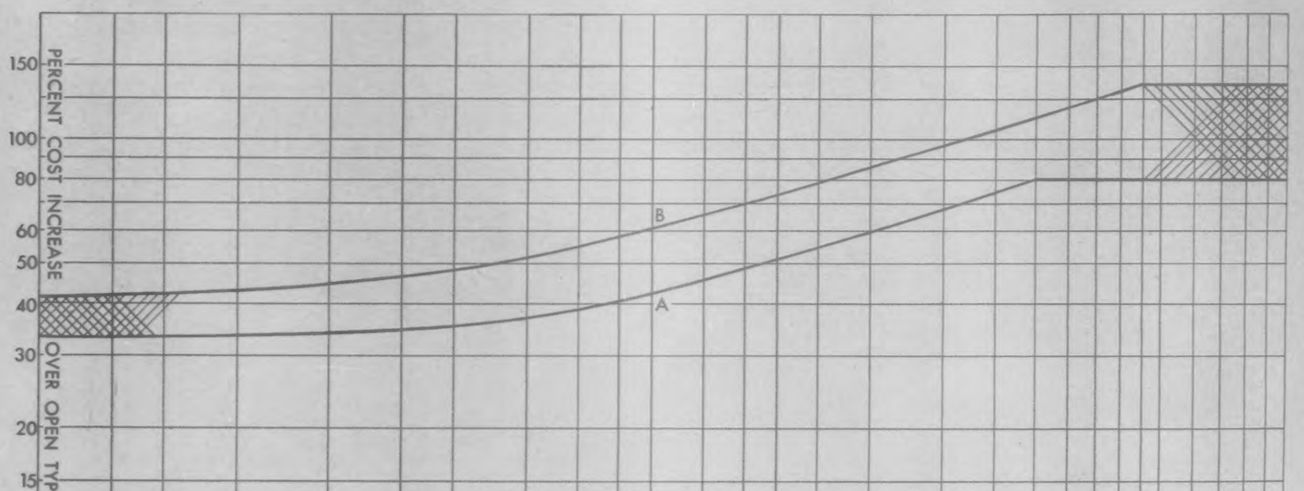
Economic considerations

Totally enclosed, fan-cooled motors, standard or explosion-proof, have a greater first cost than those with simpler protective features, such as drip-proof, drip-proof protected, splash-proof, etc. The cost differential becomes greater as the rating increases (Figure 11). Many plants have locations where motors with various degrees of protection may be used effectively, to suit each particular drive requirement. However, if conditions were such that a greater proportion of the plant drives required totally enclosed, fan-cooled motors of one class or another, then, from the standpoint of maintenance and interchangeability, it may prove wise to use motors of one type. Even though this may be somewhat more expensive initially, it would help to safeguard against costly shutdowns and provide for a more uniform maintenance. An analysis of plant production control, with regard to material flow and continuity of operation, would show the value either for or against such standardization. It is no exaggeration to say that in certain continuous process applications a relatively short-time shutdown may so choke production, or cause such loss of materials, that the cost exceeds the initial capital charge for the fan-cooled type of motor.

Conclusion

In this series of articles an endeavor has been made to present, in a matter of fact way, the enclosure and protection features for general purpose and larger rotating machines. The protection of rotating machinery is strictly an economic proposition throughout and follows the principle of increasing or diminishing returns upon the investment. In general, then, it is of much greater concern to the user to assure himself of adequate protection than it is to the manufacturer who probably would be much happier with a lesser number of types. The ultimate value of adequate protection depends upon the evaluation of such things as expected machine life relative to its depreciation, insurance rates, safety regulations, legal requirements, product refinement, and safeguard of life and limb. Industry realizes that appropriate protection pays dividends in reduced overall cost and that a study of problems involved is worth while in any plant.

CURVE CHART INDICATES and compares the approximate range of cost ratios between open type 40 degrees C rise motors and 55 degrees C rise totally-enclosed, fan-cooled standard motors, ranging from A for the two-pole units to B for the lower speeds. **(FIGURE 11)**



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Do You Need General-Purpose, squirrel-cage motors from 1 to 200 hp? Get in touch with your nearby Allis-Chalmers *Authorized Dealer* or District Office. Either may be able to help you from stock right now!

But For Really Big Motors — 250 to 25,000 hp and over — call your Allis-Chalmers *field engineer*. He's an *expert* on motors—can help you solve difficult drive problems, involving large or small motors, in the most economical manner.

Want Reliable Information on motor delivery? Call *either* your Allis-Chalmers dealer or district office. They have *up-to-the-minute* delivery information available to them!

The Delivery Picture's getting brighter! Our motor-building capacity has been greatly increased. We've put new methods, new equipment to work to turn out *more* motors for industry, faster!

Motor "Headquarters"—½ to 25,000 hp and Up!

YOU SELECT from a *wide range* of motors when you call on Allis-Chalmers. And you can count on *expert* motor advice, too! The best possible motor selection is the result of careful appraisal of drive characteristics, the driven equipment, power source and surroundings. The best motor may not always be the first that meets the requirements.

Allis-Chalmers authorized motor dealers or factory representatives can help you choose wisely. They can save you time and money. ALLIS-CHALMERS, MILWAUKEE 1, WIS. A 2401

ALLIS-CHALMERS

One of the Big 3 in Electric Power Equipment—Biggest of All in Range of Industrial Products